Study on Earthquake Response of Composite, Steel and RCC Structures for Addis Ababa Condominium Housing Project

By

Dagem Mersha

Addis Ababa Science and Technology University
College of Architecture and Civil Engineering
of Post Graduate Studies

In Partial Fulfillment of the Requirement for Degree of Master of Science in Structural Engineering

June-2017

CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Science and Technology University a dissertation entitled "**Study on Earthquake Response of Composite, Steel and RCC Structures for Addis Ababa Condominium Housing Project***”* in partial fulfillment of the requirement for the degree of Master of Science in Structural Engineering.

____

Dr. Suresh Borra

Principal Advisor

DECLARATION

It is hereby declared that the works contained in this thesis is the research work carried out by the author under the supervision of Dr. Suresh Borra. Neither this thesis nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

Dagem Mersha

APPROVAL PAGE

This Msc thesis entitled with **"Study on Earthquake Response of Composite, Steel and RCC Structures for Addis Ababa Condominium Housing Project"** has been approved by the following examiners in partial fulfillment of the requirement for the degree of Master of Science in **Structural Engineering**.

Date of Defense: June, 2017

Principal Advisor

1. Dr. Suresh Borra	___________________	_________________
	Signature	Date

Members of the Examining board:

1. Dr. Asnake Adamu	___________________	_________________
External Examiner	Signature	Date
2. Dr. Temesgen Wondimu	___________________	_________________
Internal Examiner	Signature	Date
3. Mr. Simon G/Egziabher	___________________	_________________
Head , Civil Eng'g Department	Signature	Date
4. Dr. Brook Abate	___________________	_________________
Dean, College of Architecture and Civil Engineering	Signature	Date

ACKNOWLEDGEMENT

All praises to God who bestowed His Mercy upon me to complete this work successfully. It is indeed a great pleasure and also a great privilege for me to express my deepest gratitude to Dr. Suresh Borra, for his inspiration, encouragement, proper guidance and invaluable suggestions to carry out the research work. His initiative, high appreciation and encouragement to perform research in the field of my interest are highly acknowledged.

Most deserving of special recognition is for my family who was my source of inspiration and helped me sacrificing their share of family life. My deepest appreciation and thanks for their patient, unconditional love, mental support, sacrifice and help, without which this work could not have been materialized.

Table of Contents

List of Tables

List of Figures

ABSTRACT

Reinforced concrete framed structures are widely used in Ethiopia. But there are alternative options for designers to decide structural system for a particular building. Comparative study of RC, steel and composite framed condominium buildings is done in this paper to evaluate better structural system regarding overall economy, structural performance, construction time etc. To conduct the intended research work, architectural layout plan of G+15 condominium building with two basements from Addis Ababa housing development office is selected which is located in Ayat. Structural modeling and analysis have been performed by ETABS 2016. Loads are assigned following the EBCS EN 1992-2013. The research outcome shows that the fundamental period (First mode time period) of RC structure is about 36% lower than steel structure and 16% higher than Composite structure. The maximum roof displacement for the X-direction for RC structure is 41% lower than steel structure and 26% higher than that of Composite structure. The maximum roof displacement for the Y-direction for RC structure is 55% lower than steel structure and 31% higher than that of Composite structure. And cost of composite structure is 5% lower than RC structure. RC Structure for earthquake response in the X-direction base shear shows 1.1% decrease when compared to the composite structure. For earthquake response in the y-direction the base shear in RC structure shows 4.8% increase when compared composite structure. The maximum axial load for RC structure is 11% higher than steel structure and 7% higher than that of Composite structure.

Chapter 1
INTRODUCTION

1.1. General

Worldwide different types of RC and steel structures with various floor systems are being used for multistory buildings. In the past, masonry structures were widely used for building construction. Day by day technology has developed. Later, steel structural systems were started for multistory buildings. With the introduction of reinforced concrete, RC structural systems started for multistory building construction. With the advent of welding, it became practical to provide mechanical shear connectors to consider composite action. Due to failure of many multi-storied and low-rise RC and masonry buildings due to earthquake, structural engineers are looking for the alternative methods of construction. Use of composite or hybrid material is of particular interest.

These days, steel and composite structures are being popular. So, alternative structural systems are gradually developing to compete with RC structural systems In Addis Ababa. Mostly RC structures are being used. Nowadays, RC structure is dominating and steel structure is entering gradually for multistory building structures in Addis Ababa. So, comparative study is required to identify most effective structure.

Addis Ababa city government in recent years has built thousands of condominium housings. But still millions of people are registered and waiting for their turn. Mainly reinforced concrete is used for construction in these projects. The first design was G+2,G+3 & G+4. Now it has new design of G+15 & G+20. As the number of floors increase; using reinforced concrete will become uneconomical because of its lower strength-to-weight ratio. And it will take more time to execute since it needs curing.

Currently steel structures and composite of steel and concrete has become accepted in developed countries. It has many advantages using steel structures in our country. It will give new alternative materials for the construction industry so it will create more new jobs for the community. The steel industry will also get a new market so it will give lift for the economy. On the other hand steel industry needs advanced technology and this will give the country a new dimension of transformation. It is also advantageous for reducing Curing time since RCC structures take more time to be cured. And this will reduce the construction time.

1.2. Background

1.2.1. Reinforced Concrete

Reinforced concrete generally consisting of Portland cement, water, construction aggregate (coarse and fine), and steel reinforcing bars (rebar), concrete is cheaper in comparison to structural steel.

Concrete is a composite material with relatively high compressive strength properties, but lacking in tensile strength. This inherently makes concrete a useful material for carrying the weight of a structure. Concrete reinforced with steel rebar give the structure a stronger tensile capacity, as well as an increase in ductility and elasticity.

Reinforced concrete must be poured and left to set, or harden. After setting (typically 1–2 days), a concrete must cure, the process in which concrete experiences a chemical reaction between the cementations particles and the water. The curing process is complete after 28 days; however, construction may continue after 1–2 weeks, depending on the nature of the structure. Concrete can be constructed into nearly any shape and size. Approximately half of the cost of using reinforced concrete in a structural project is attributed to the construction of the form-work. In order to save time, and therefore costs, structural concrete members may be pre-cast. This refers to a reinforced concrete beam, girder, or column being poured off site and left to cure. After the curing process, the concrete member may be delivered to the construction site and installed as soon as it is needed. Since the concrete member was cured off location beforehand, construction may continue immediately after erection. **(Handbook of Structural Engineers, 1997)**

Concrete has excellent fire resistance properties, requiring no additional construction costs to adhere to the International Building Code (IBC) fire protection standards. However, concrete buildings will still likely use other materials that are not fire resistant. Therefore, a designer must still take into account the use of the concrete and where it will require fire hazardous materials in order to prevent future complications in the overall design. **(Handbook of Structural Engineers, 1997)**

Reinforced concrete, when constructed properly, has excellent corrosion resistance properties. Concrete is not only resistant to water, but needs it to cure and develop its strength over time. However, the steel reinforcement in the concrete must not be exposed in order to prevent its corrosion as this could significantly reduce the ultimate strength of the structure. **(Handbook of Structural Engineers, 1997)**

1.2.2. Steel Structure

Steel differs from concrete in its attributed compressive strength as well as tensile strength.Having high strength, stiffness, toughness, and ductile properties, structural steel is one of the most commonly used materials in commercial and industrial building construction.

Structural steel can be developed into nearly any shape, which are either bolted or welded together in construction. Structural steel can be erected as soon as the materials are delivered on site, whereas concrete must be cured at least 1–2 weeks after pouring before construction can continue, making steel a schedule-friendly construction material.

Steel is inherently a noncombustible material. However,when heated to temperatures seen in a fire scenario, the strength and stiffness of the material is significantly reduced. The International Building Code requires steel be enveloped in sufficient fire-resistant materials, increasing overall cost of steel structure buildings. **(Handbook of Structural Engineers, 1997)**

When in contact with water, steel can corrode, creating a potentially dangerous structure. Measures must be taken in structural steel construction to prevent any lifetime corrosion. The steel can be painted, providing water resistance. Also, the fire resistance material used to envelope steel is commonly water resistant. **(Armstrong, 2014)**

Steel can undergo large plastic deformation before failure, thus providing large reserve strength. This property is referred to as ductility. Properly designed steel structures can have high ductility, which is an important characteristic for resisting shock loading such as blasts or earthquakes. Steel in fact shows elastic behavior up to a relatively high and usually well-defined stress level. Also, in contrast to reinforced concrete, steel properties do not change considerably with time. But due to high strength/weight ratio, steel compression members are in general more slender and consequently more susceptible to buckling than, say, reinforced concrete compression members. **(Patil V., 2015)**

1.2.3. Combining steel and reinforced concrete

Though Steel and concrete materials may have different properties and characteristics, they both seem to complement each other in many ways. Steel has excellent resistance to tensile loading but lesser weight ratio so thin sections are used which may be prone to buckling phenomenon. On the other hand concrete is good in resistance to compressive force. Steel may be used to induce ductility an important criteria for tall building, while corrosion protection and thermal insulation can be done by concrete. Similarly buckling of steel can also be restrained by concrete. In order, to derive the optimum benefits from both materials composite construction is widely preferred. **(Patil V., 2015)**

Material property has great effect for seismic load. In order to resist lateral forces lateral resisting members like columns should be large in RC structure because of its low strength to weight ratio this will increase the base shear on the structure. Ductility and elasticity is high in steel structures when compared to RC structures. Since the strength to weight ratio in steel structure is high the weight of the structure is low. So thin sections are used which it may be prone to buckling phenomenon. Buckling is a major failure of structural steel for large structures in seismic zone. In order to have both material properties using steel concrete composite structure is important. The high compressive strength of concrete will resist structural steel from buckling. The concrete in composite structures make the structure stiffer than steel structures. Composite structure is highly ductile compared with RC structure. This ductility property of composite structure makes it a better material for large structures in seismic zone region.

1.3. Objectives of the Research

Objective of this research are:-

- To compare Earthquake response of RCC, steel and composite structures for G+15 condominium building.

- to obtain the cost of G+15 building of RCC, steel and composite structures and compare the result.
- Investigate the feasibility of RCC, steel and composite structures.
- And finally to give recommendations after result.

1.4. Significance of the Study

The number of researches done in Ethiopia about Steel and composite structures is very limited therefore this paper will be very helpful for examining the Earthquake response and economic advantage gained from using steel and composite structures on Condominium projects. It is also important for investigating the adoptability of Steel and composite structures in our countries current situation.

1.5. Scope of Work

A G+15 condominium design from Addis Ababa housing project is selected. The typical floor height is 3 meter. The Analysis of this building of RCC building is formed. Using the same plan, the analysis is also done for steel and composite. Dynamic analysis is performed. Lateral displacement, mode Shape, Time period, Base Shear, Axial forces are observed to evaluate the better structural system for the selected Condominium building,

1.6. Outline of Methodology

To conduct the intended research work, architectural layout plan of a fifteen story residential building is selected from Addis Ababa housing designs. Following the plan, RC structure, Steel and composite structures are formed. Then three dimensional structural modeling and dynamic analysis have been performed by ETABS 2016 for the three types of structural system. Loads are assigned as per EBCS EN 1992-2013. Load combinations are generated regarding EBCS 2, EBCS 3 and EBCS 4. Comparisons of seismic structural behaviors have been prepared to evaluate better/ most effective structural system for the building used for this research.

The summarized methods for this research are as follows:-

- Reviewing different literatures.
- Reviewing structure already done at Addis Ababa housing development

- Analyzing the structure with three materials RCC, steel and composite and compare the output of dynamic analysis.
- Make conclusion based on the result and give recommendation.

1.7. Organization of the Thesis

The thesis consists of five chapters.

Chapter one presents an introduction to the study. It includes the research background, objectives, scope of work and outline of methodology.

Chapter two describes previous works done on the comparison of the conventional RC frame, steel frame and composite frame.

Chapter three deals with complete methodology of the research work. It illustrates architectural planning and structural formation of selected building, load calculations, structural modeling, structural analysis and design and preparation of tables for different design results.

Chapter four deals with result and discussion of all data obtained from the design program performed in chapter 3 to compare evaluate and draw findings and conclusions of the research work.

Chapter five deals with conclusions and recommendations of the research work.

Chapter 2
LITERATURE REVIEW

2.1. Introduction

This chapter will mainly focus on literatures on RCC, steel and composite structure. Comparison of these materials in different literatures is discussed. Time period, cost analysis, base shear and lateral deflection comparison in different literature are discussed in detail in section 2.2. The local industries steel production is also been discussed. Sections available imported by local factories from literatures is shown in section 2.3.

2.2. Comparative Studies

2.2.1. Time period

The time an object takes to vibrate back and forth to one complete cycle is known as Time period. It is one of the most important factors determining how a structure will respond to ground shaking.

Kumawat M.(2014) work steel concrete composite with RCC option are considered for comparative sturdy of G+9 story commercial building which is situated in seismic zone. SAP 2000 software is used for the analysis. In their result reduction in time period in composite shown when compared to RCC. Reduction is between 14%-29% in 12 modes selected.

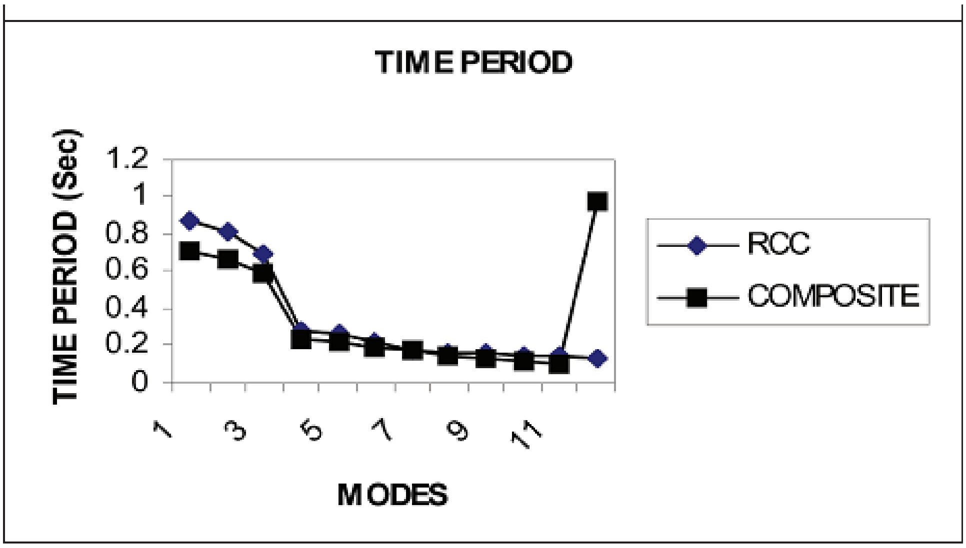

Figure 2.1 Comparison of Time period (Kumawat M., 2014)

Prof. S.S Charantimath(2014), work study of state of art of seismic performance is evaluated for RCC and composite structures of 10 story, 20 story and 30 story building. Analytical study on the structural behaviour of RCC and composite high rise building is under taken. Equivalent static method is use for analysis and ETABS 2013 software is used.

Composite structure show 11.43% and 4.04% lower than RCC for 10 and 20 story buildings for earth quake in the x-direction. But result shows 14.10% higher in composite structure for 30 story building than RCC. For earthquake in the y-direction 12.31% and 3.01% reduction is shown in the composite structure for 10 story and 20 story than equivalent RC structure. Composite is 10.86% higher than RCC for 30 story building.

Prof. Swapnail B.(2015), tried to compare G+9 multi-storied RCC and composite structures by using both Equivalent static and Response spectrum method are used to analyze the building. SAP 2000 software is used for analysis. The first mode of time period for composite structure is lower than RCC structures by 4.2%.

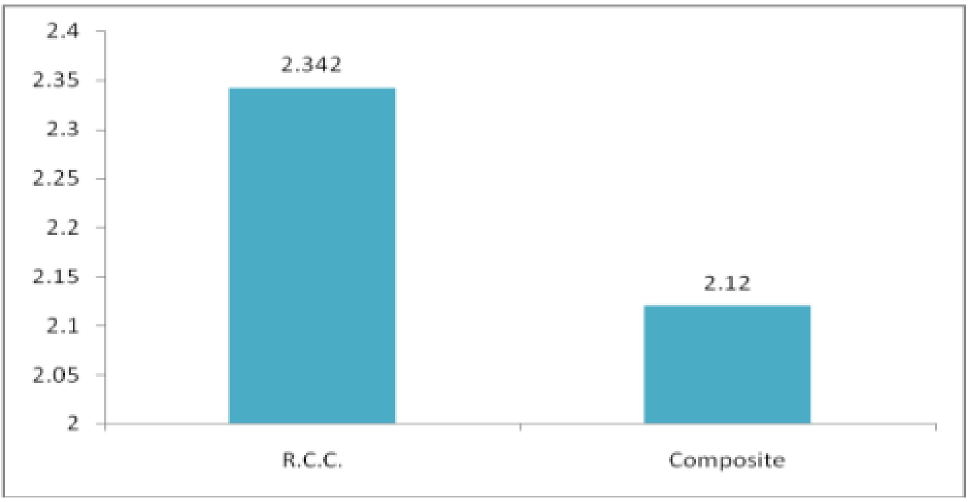

Figure 2.2 Comparison of Time period (Prof. Swapnail B., 2015)

Patil V.(2015), provide structural analysis of composite, RCC and steel structure when subjected to earth quake for comparative study of G+5 story commercial building is taken. ETABS 2013 software is used to carry out the analysis. The increase stiffness of composite structure results in increased reduction in time period than RCC and Steel.

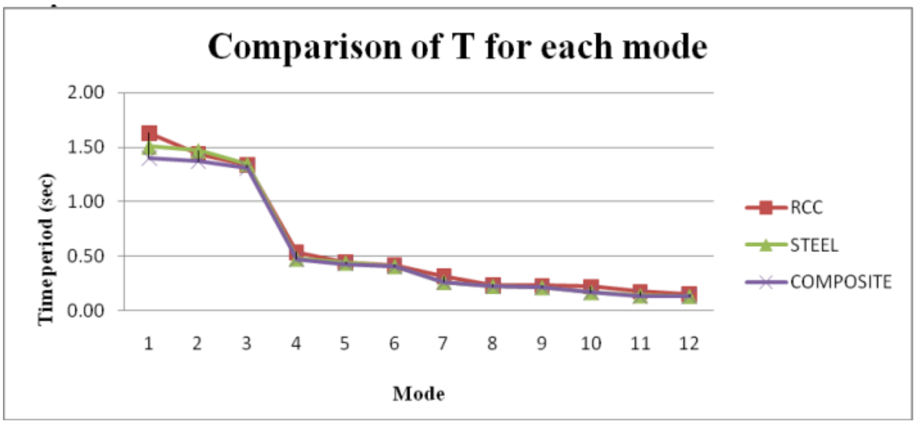

Figure 2.3 Comparison of Time period (Patil V., 2015)

Jirage D.(2015), work steel concrete composite with RCC are compared to study a G+20 story building which is situated in seismic zone. Equivalent static method and response spectrum method of analysis is used. For modeling of composite and RCC structures ETABS software is used and the results are compared. Time period in composite structure shows 18% increase than that of RCC structure.

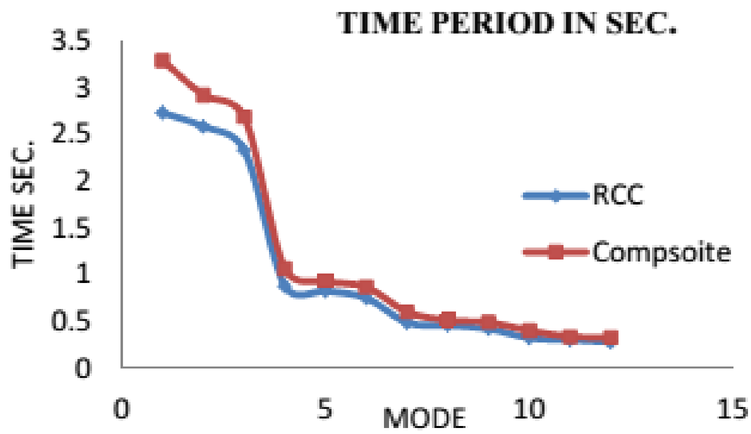

Figure 2.4 Comparison of Time period (Jirage D., 2015)

In the above literatures most results show that RC has higher time period than composite structures.But for **Prof S.S Charantimath(2014)** result for the 30 story building shows that composite structure has higher time period than that of RCC. In **Jirage D.(2015)** result of G+20 building composite structure shows higher time period value than RCC structure.

2.2.2. Displacement

Kumawat M.(2014), the lateral displacement of the commercial G+9 building selected shows for response spectrums analysis spectrum analyzed. In composite structure it reduced up to 46%-58% and 45%-56% in transverse and longitudinal direction respectively when compared to RCC structure.

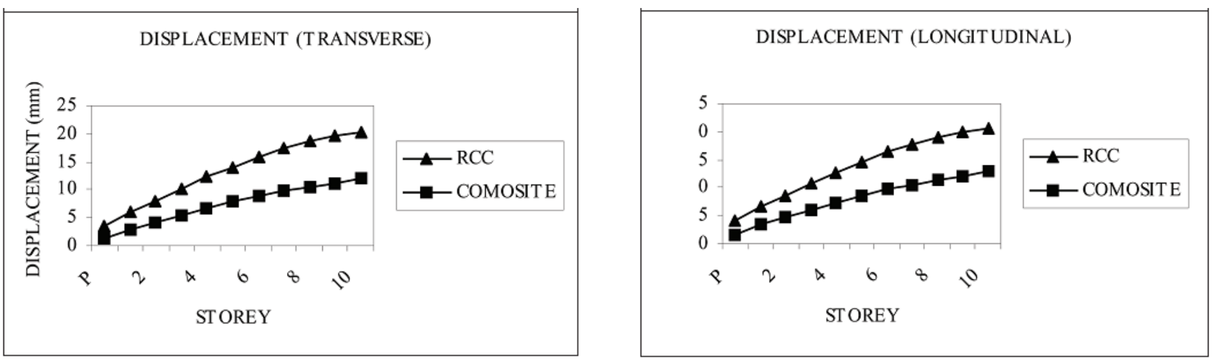

Figure 2.5 Comparison of lateral deflection in the X and Y direction (Kumawat M., 2014)

Najia A.(2016), work compares a twenty storied RCC and composite framed structure frame with Buckling restrained braced frame subjected to seismic and different temperature loading using non-linear time history analysis. Three dimensional modeling and analysis of the structure is carried out with the help of SAP 2000 software.

Result in the study shows storey displacements were decreased by 36% for twenty story RCC building and for composite building it was decreased by 45% for twenty stories suggesting the effectiveness of buckling restrained brace frame.

Kumar M.(2016), compares 5 story, 10 story and 15 storied RCC and composite structures are considered in seismic zone. The seismic behaviour is evaluated by using response spectrum and non-linear time-history analyzed by ETABS software.

The displacements of the structure are reduced from composite to RCC as shown. The displacements is reduced from 30.8 mm to 20.6 mm in low rise (5 story) structure,49.9 mm to 29.8 mm in medium rise (10 story) structure, and 75.1 mm to 33.79 mm in high rise(15story) structure in X-direction and 31.8 mm to 22.4 mm in low-rise(5 story) structure, 51.3 mm to 32.6 mm in med-rise (10 story) structure, and 76.5 mm to 34.42 mm in high rise(15story) structure in Y-direction.

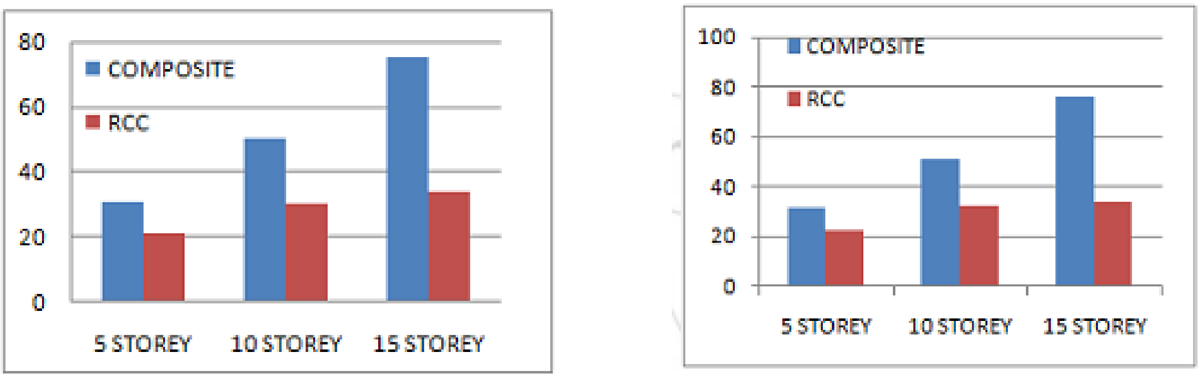

Figure 2.6 Comparison of lateral deflection in the X and Y direction (Kumar M, 2016)

Prof. Swapnail B.(2015), in the 9 story building joint displacement of composite structures represent lower values of displacement than RCC structures. Joint displacement in X-direction in composite structures is reduced by 18.36% and 14.3% after analyzing it by both equivalent static and response spectrum analysis methods respectively. Similarly in the y-direction it reduced by 16.52% and 12.58% respectively.

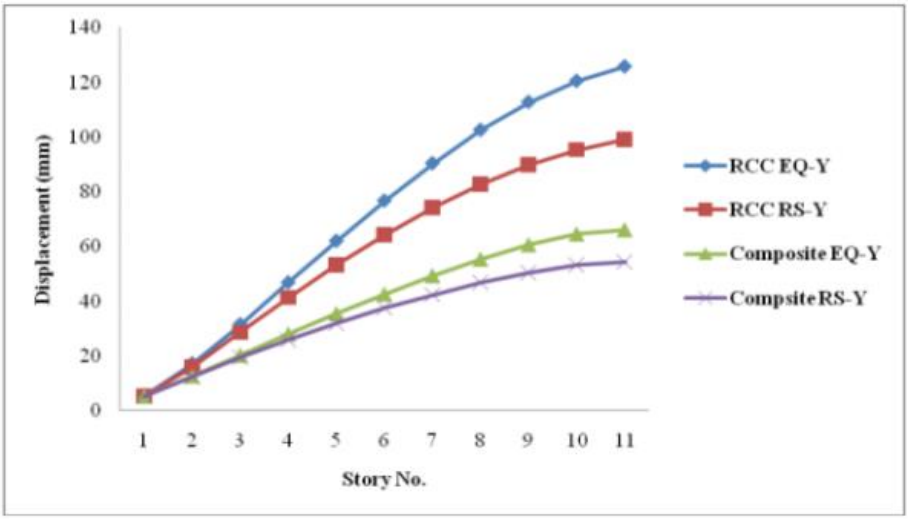

Figure 2.7 Comparison of dynamics and static analysis deflection in the X and Y direction (Prof. Swapnail B., 2015)

Koppad S.(2013), analyzed steel concrete composite with RCC options are considered for comparative study of B+G+15 story of residential building which is situated in earthquake zone. STAAD-pro software is used for analysis.

From the analysis result node displacement for composite is 39% higher than that of RCC in the roof top.

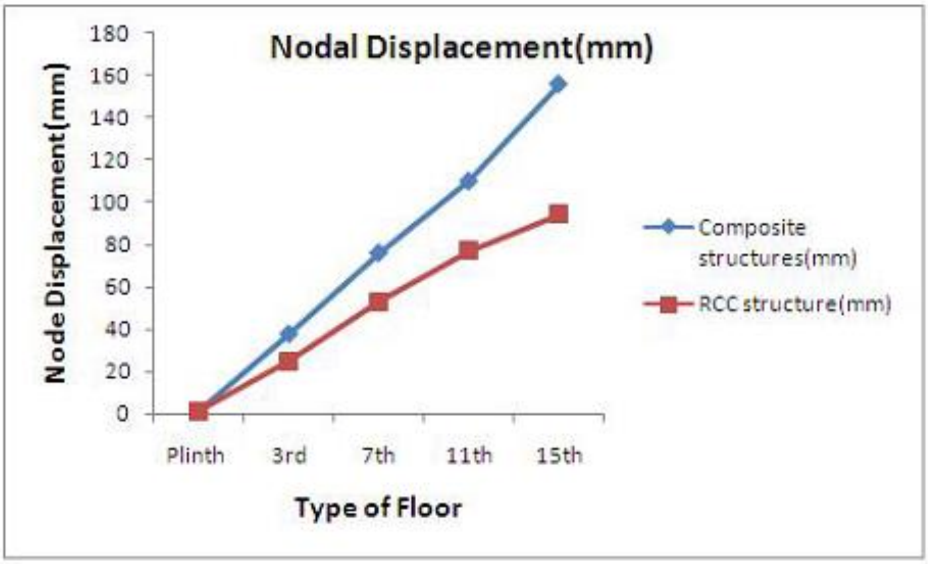

Figure 2.8 Comparison of lateral deflection (Koppad S., 2013)

Patil V.(2015), in the five story building the story displacement in the X-direction shows that composite structure is 25% and 1.5% lower compared to RCC and steel building. Similarly in the Y-direction it shows 14% and 7.8% lower compared to RCC and steel.

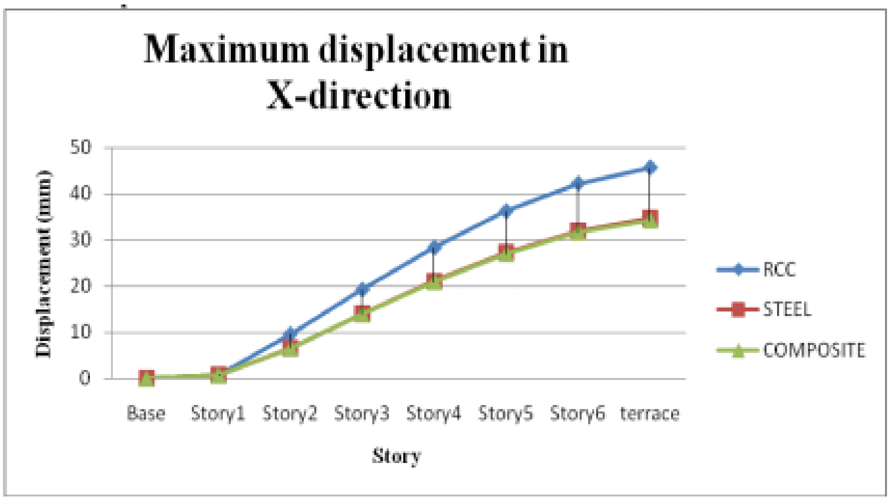

Figure 2.9 Comparison of lateral deflection in the X-direction (Patil V., 2015)

The above literatures get different results with regard to story displacement. **Prof. Swapnail(2015) B., Patil V(2015)., Kumawat M(2014)** and **Najia A(2016)** results in their literatures show that composite structure has low nodal displacement when compared to an equivalent RCC framed structure. But in **Koppad(2013) S**and **Kumar M.(2016)** literatures result shows that composite structure has higher nodal displacement.

2.2.3. Cost analysis

Aniket R.(2016), paper involves analysis of a residential building with steel-concrete composite and RCC construction. The paper compares analysis result of G+9, G+12, G+15 and G+18 buildings. STAAD-pro 2007 is used for modeling and analysis. Cost comparison is done for Composite and its equivalent RCC structure. The cost estimate result shows RCC structures are more expensive than Composite structure. For G+15 stories building RCC shows 48% increase when compared to equivalent composite structure. Similarly G+18 shows 57% increase.

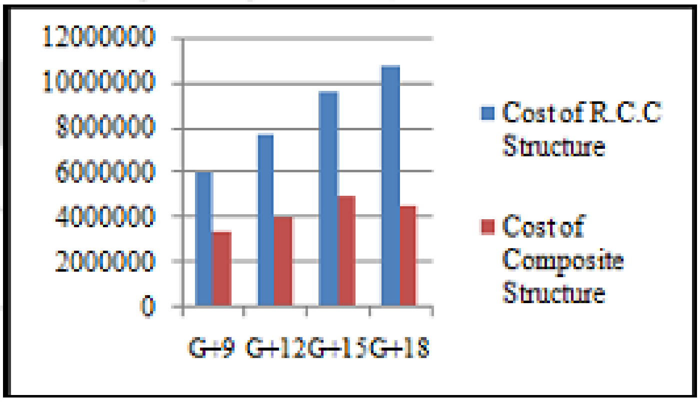

Figure 2.10 Comparison of cost (Anujet R., 2016)

Begum M.(2013), Cost comparison of RCC building and composite building for different storey heights are taken in to consideration. G+6, G+12, G+18 and G+24 story structures are taken for the comparison. For the 18 story and 24 storied building the cost of RCC structure exceeds the cost of composite structure by 4% and 14% respectively.

Generally in the literatures composite structures cost for mid-rise to high-rise building is lower than RCC structures.

2.2.4. Base shear

Jirage D.(2015), G+20 story building shows comparison of base shear in composite structure is reduced by 20% as compared with RCC structure.

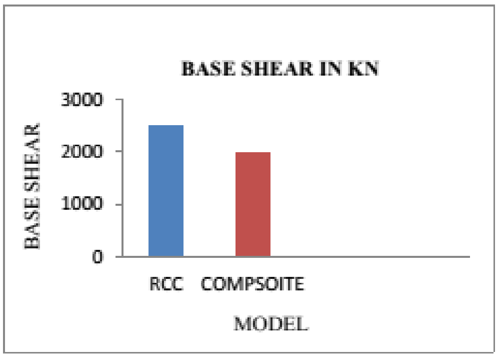

Figure 2.11 Comparison of Base shear (Jirage D., 2015)

Prof S.S Charantimath(2014), in G+10 story frame structure the design base shear EQx are decreased by 26% in composite structure as compared to EQX in RCC framed structure.

Prof. Swapnail B(2015)., the nine story building shows design base shear value in X-direction for composite structure is decrease by 18%. The structure in the Y-direction also show 18% decrease.

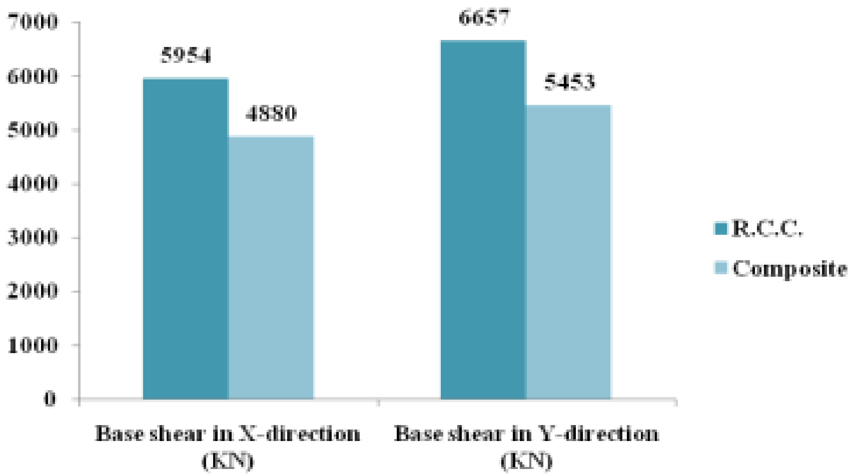

Figure 2.12 Comparison of Base shear (Prof. Swapnail B., 2015)

Patil V.(2015), five story building equivalent static method of analysis shows base shear in composite structure is lower than RCC by 30% while steel by 2%.

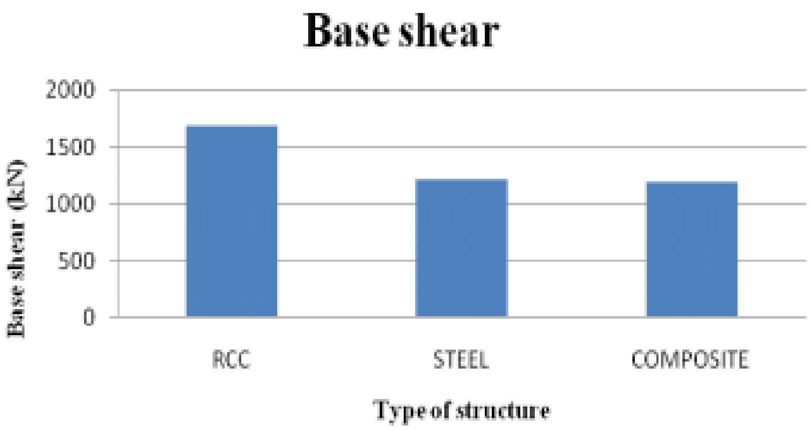

Figure 2.13 Comparison of Base shear (Patil V., 2015)

In the literatures base shear in composite structures have lower value when compared to RCC structure due to it high strength to weight ratio.

2.2.5. Axial Load

Prof S.S Charantimath(2014) work compared axial load of corner column of composite and RCC structures for 10, 20 and 30 story buildings. He found a result for 10, 20 and 30 stories building the axial forces on corner composite column is reduced by 24.55%, 27.28% and 40.61% than that of RCC corner column respectively.

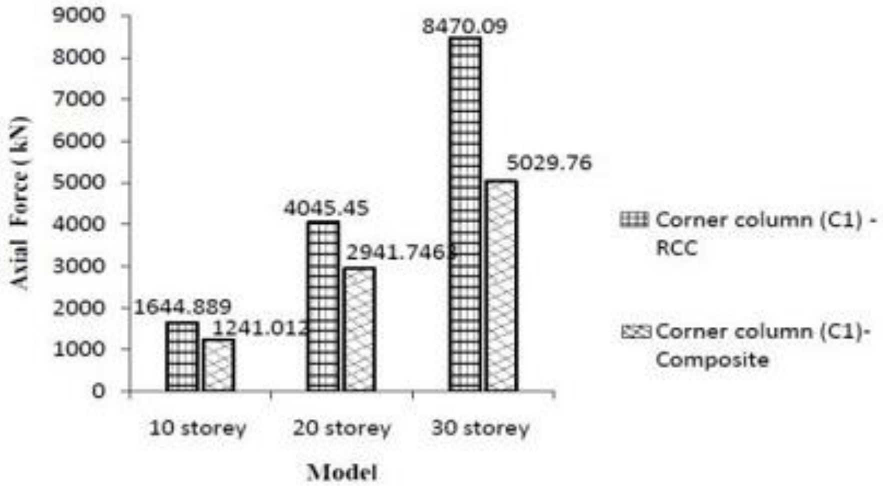

Figure 2.14 Comparison of Axial Force (Prof S.S Charantimath, 2014)

Kumawat M.(2014) 9 story commercial building compared and axial load of RCC and Composite structures. Axial force in all composite columns is reduced by 18% to 30% than RCC columns. Shear force in exterior columns is observed to be more than interior columns in transverse direction and for composite columns it is reduced by 31% to 47%.

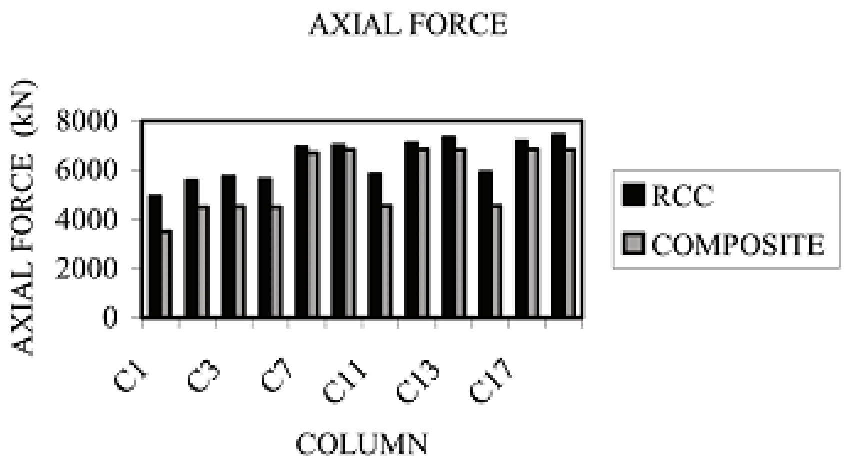

Figure 2.15 Comparison of Axial Force (Kumawat M., 2014)

Jirage D.(2015), literature also shows G+20 building axial force for corner column for RC and Composite structure is compared. Composite structure is less as compare with RCC by 18%, because the self wt. of the RCC structure is more.

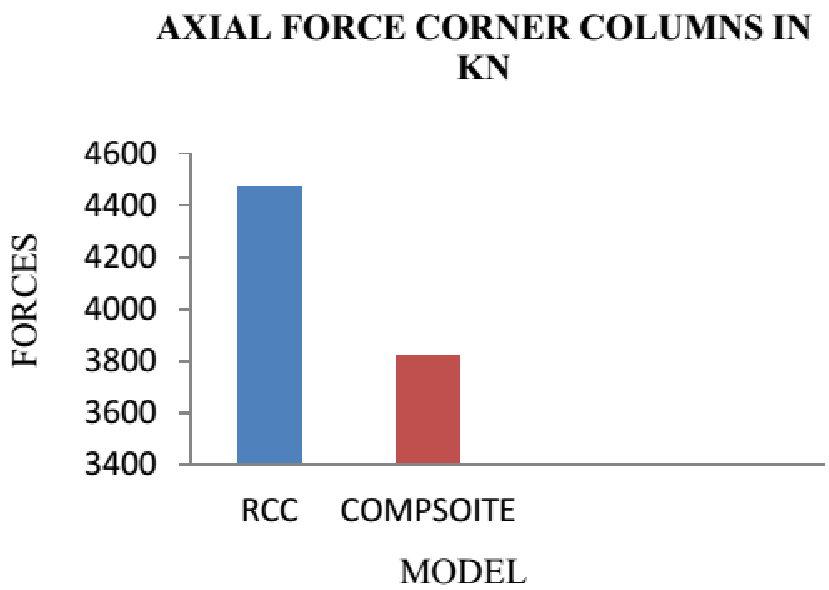

Figure 2.16 Comparison of Axial Force (Jirage D., 2015)

Aniket R.(2016) work analyzed and compares RC framed section with steel frame section for 12, 15 and 20 story buildings. It shows that RC framed structure have more axial force than that of steel framed structure.

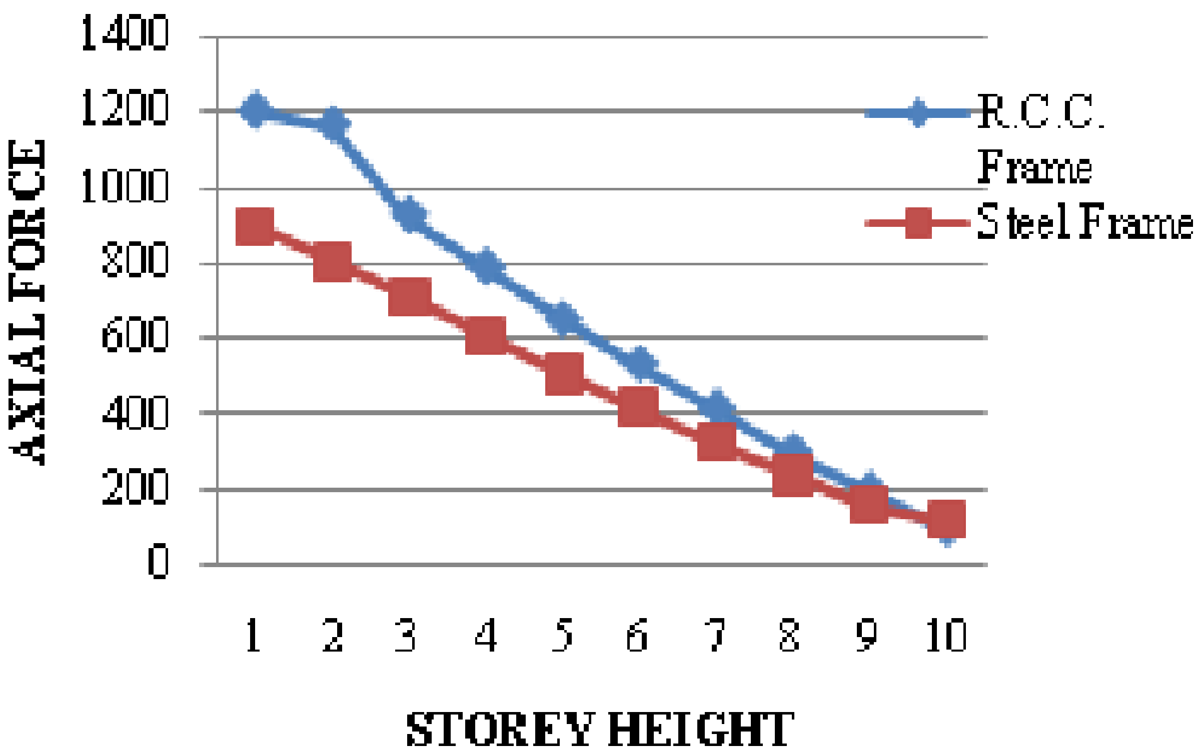

Figure 2.17 Comparison of Axial Force (Aniket R., 2016)

In all the literatures results shows axial force of RC structures are more than that of composite structure. This is because weight of structure in RC structure is more than Composite structure.

2.2.6. Weight of Structure

Jirage D.(2015), in the literature G+20 Weight of structure of RC and Composite compared. Weight of Composite structure is reduced by 23% as compared with RCC Structure.

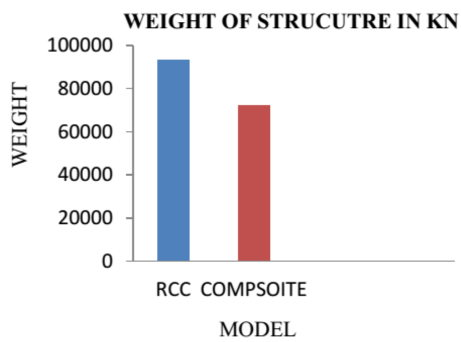

Figure 2.18 Comparison of Weight (Jirage D., 2015)

Prof. Swapnail B.(2015), the nine story building shows self-weight of composite Structures having mass irregularity at 9th floor is decreased by 16%.

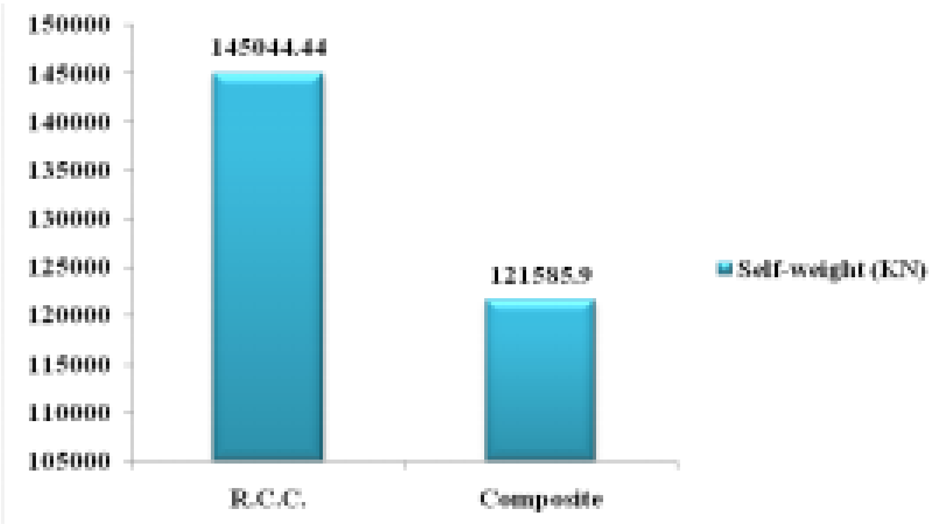

Figure 2.19 Comparison of Weight (Prof. Swapnail B.,2015)

Weight of composite structure is expected to reduce when compared to RC structures. In the literatures results also show composite structures have lower weight than RC structures.

2.3. Steel Production in Ethiopia

Even though local industries has been manufacturing steel profiles, it has been using for car bodies and mainly roofing and cladding purposes. This technology is not highly adapted in structures in Ethiopia due to different reasons. One of the main advantage of this construction technology is that its economic benefit.

The Table below shows that the range of sizes of steel sheets imported by local factories for the production of construction materials such as rectangular and circular tubes, tankers, profiled steel sheets, etc. The entire locally manufactured profiled steel sheets' standard forms are the same. These forms of profile sheets i.e. EGA-300, EGA-400, EGA-500, EGA-600 & EGA-700 have been hardly used for composite slab construction for buildings.**(Redie R., 2003)**

Table 2-1 Type of sheet metals imported by local factories (Redie R., 2003)

Item No.	Production Firm	Steel Sheet Type	Sheet Metal Thickness in mm	Plan Dimension
1	Kality Metal Factory	Galvanized steel sheets	0.25,0.3,0.4,0.5,0.6,0.7,0.8, & 1.0,1.5	One meter width in coils
		Non-galvanized steel sheet	0.8,1.0,1.2,1.5,1.6,1.8,2.0,2.5 & 3.0	One meter width in coils
			4.0,5.0,6.0,8.0,10.0,12.0	1 meter side & 2.0 meter length
2	GATERPRO Metal Industry	Galvanized steel sheets	0.25,0.3,0.4,0.5,0.6,0.7,0.8,1.0	1 meter width in coils
		Non-galvanized steel sheet	4.0,5.0,6.0,8.0,10.0,12.0	1.5 meter width & 6 meters length
3	MaruTefera Metal Factory	Galvanized steel sheets	0.25,0.3,0.4,0.5,0.6,0.7,0.8,&1.0,1.5	One meter width in coils
		Non-galvanized steel sheet	1,5,2.0,3.0,4.0,5.0,6.0,8.0,10.0,12.0	In coils for sheets less than 4.0mm & in cut lengths for 4mm and above thickness
4	Kombolcha Steel Product Industry(KOSPI)	Galvanized steel sheets	0.25,0.3,0.4,0.5,0.6,0.7,0.8	One meter width in coils

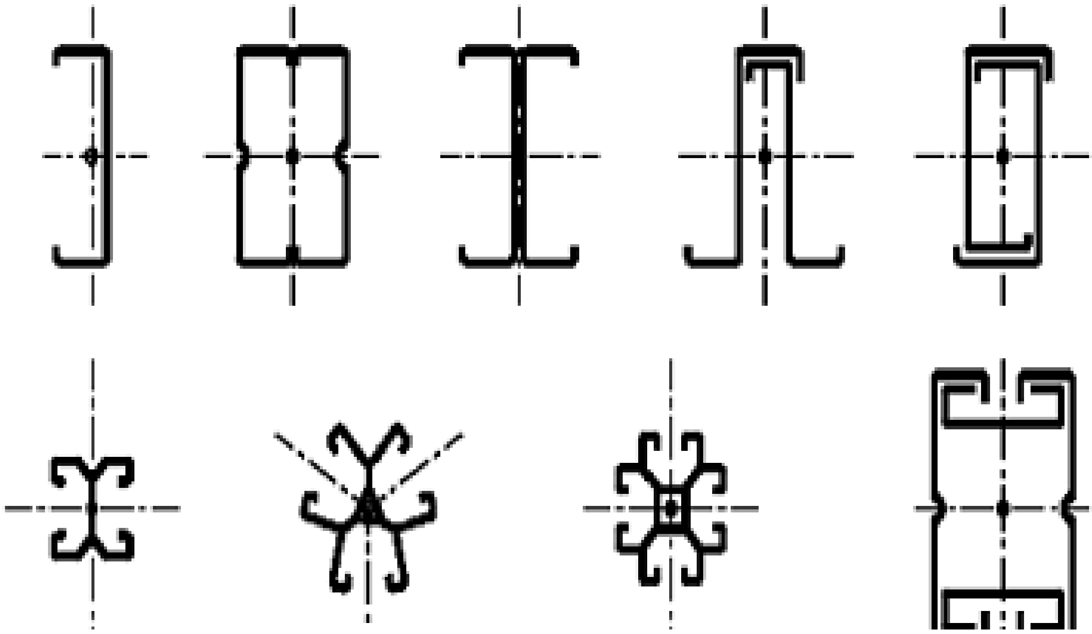

Figure 2.20 Profiled sheet, Compression and Tension Member(Redie. R, 2003)

2.4. Summary

In the above literatures most results show that RC has higher time period than composite structures. But in some of the literatures this is different. The time period is related to the ductility and stiffness of the structure. As stiffness structure gets high the time period will be low.

The above literatures get different results with regard to story displacement. Some literatures results in their literatures show that composite structure has low nodal displacement when compared to an equivalent RCC framed structure. And some literatures results showthat composite structure has higher nodal displacement.

Generally in the literatures composite structures cost and base shear for mid-rise to high-rise building is lower than RCC structures.

In all the literatures results shows axial force of RC structures are more than that of composite structure. This is because weight of structure in RC structure is more than Composite structure.

Weight of composite structure is expected to reduce when compared to RC structures. In the literatures results also show composite structures have lower weight than RC structures.

In most literatures they Contrasted analysis of RCC and Composite they all agreed that composite structures is a better alternative for high-rise buildings.In our country this technology is not adapted for different reasons. To adjust steel concrete composite material in large projects local industries in the country have to satisfy the demand of the construction industry. In this paper we used linear modal spectra analysis method. Also the conditions for Addis Ababa are different, thus we will consider this conditions and use the revised Ethiopian Building Code for Analysis. The paper will focus on comparison of earthquake response of RCC, Steel and composite structures in Addis Ababa condominium project.

Chapter 3
METHODOLOGY

3.1. Introduction

The primary objective of this chapter is to perform analysis of a fifteen storied residential building as RC, steel and composite structure with various floor systems. Finally, comparison of structural behavior of the building required to evaluate better structural system. To achieve this objective, complete architectural design of a G+15 residential building has been used, which is currently used for condominium project in Ayat Addis Ababa located shown in Figure 3.1.

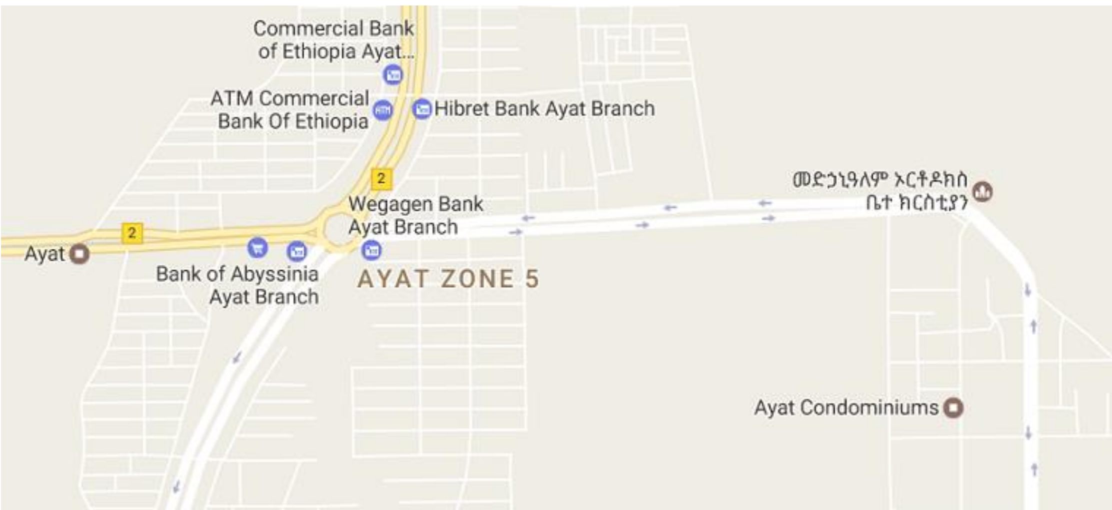

Figure 3.1Ayat Condominium location

Following the architectural plan, RC structural systems have been formed. Again following same plan, steel and composite structural systems have been formed. Then structural modeling and analysis have been performed by ETABS 2016 software for the selected three types of structural systems. Loads are assigned as per EBCS EN 1992-2013. Load combinations are generated regarding EBCS 2, EBCS 3and EBCS 4. Comparisons of seismic structural behaviors have been prepared to evaluate better/ most effective structural system for the building used for this research.

Here, formation of structural systems, load calculations, structural modeling, analysis, design, observation of structural behavior (Time period, deflection, base shear, story shear and maximum axial load) have been performed for the intended research program.

3.2. Architectural Design

Complete architectural design of a 2B+G+15 storied residential building is selected as shown in Figure 3.1 and Figure 3.3Figure 3.4.To reduce torsion effect on the structure expansion joint is provided between the stair case and the two symmetric floor systems. Expansion joint is also provided between the ramp and the structure and the structure typical floor is shown on figure 3.4. Since the structure is symmetric the analysis is carried for the floor shown Figure 3.4. Typical floor height is 3 meter.

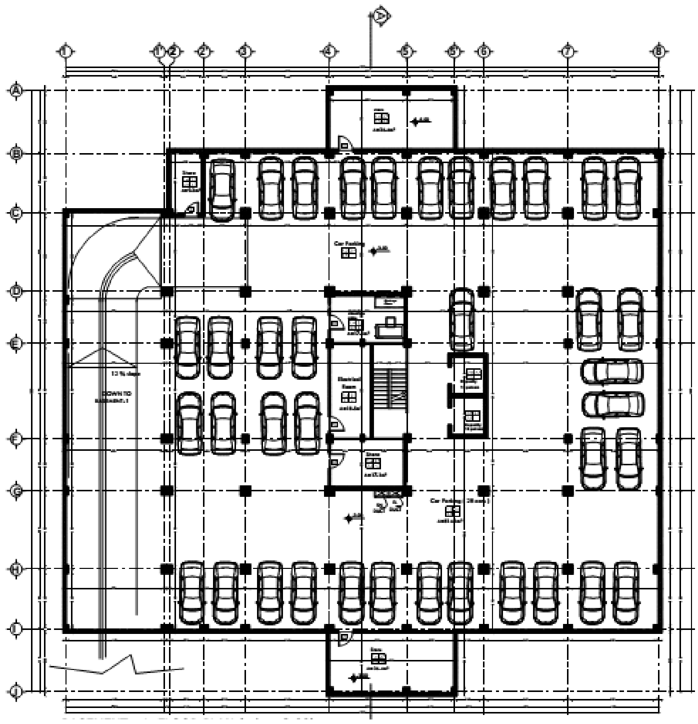

Figure 3.2 First Basement Floor Plan

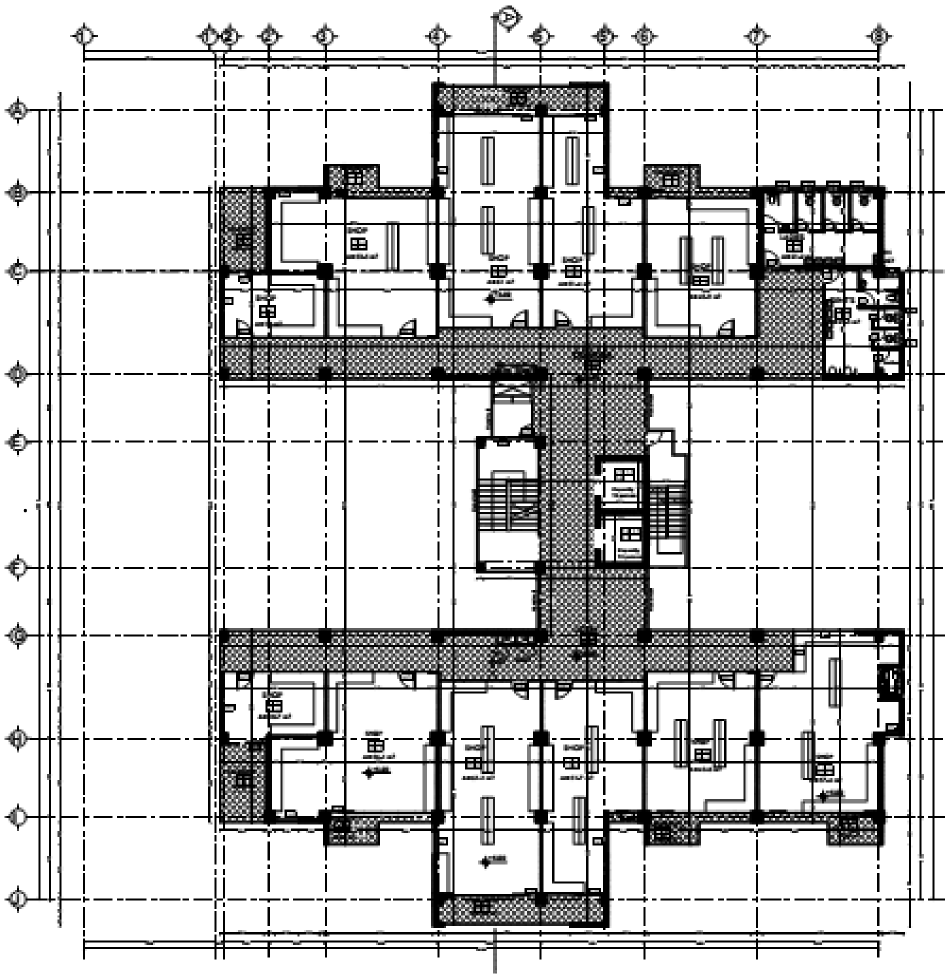

Figure 3.3 Second Floor Architectural Drawing

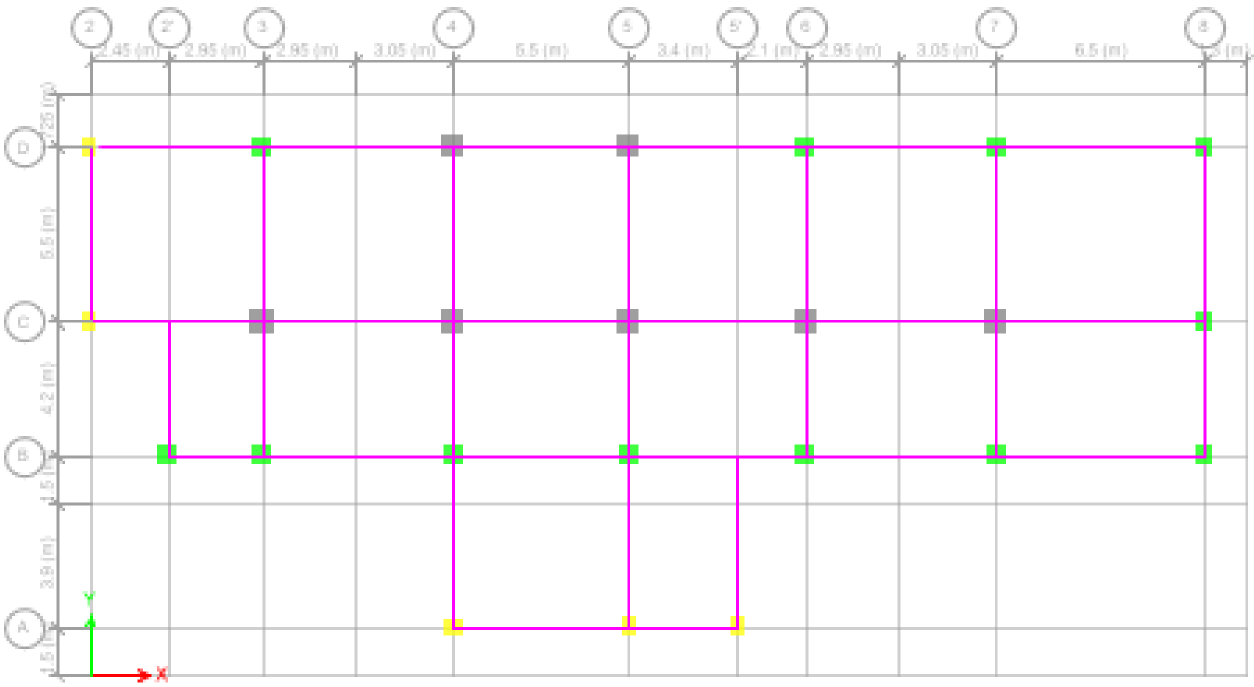

Figure 3.4 Typical Floor Plan

3.3. Structural System

On this condominium projects precast ribbed slab is mainly used. But in this analysis we used solid slab for a rigid diaphragm. But for steel and composite structure reinforced concrete slab on corrugated steel deck is formed as composite is used.

3.3.1. RC Structure

RC structural system is formed with beam supported 15cm thick solid slab for the typical floor and 17 cm solid slab for first basements and Ground floor. Structural is considered as intermediate moment resisting rigid frame with two shear walls shown in Figure 3.5. Floor slab is assumed as rigid in plane which acts as diaphragm to transfer lateral load horizontally to shear walls and column. Design section for RC structure is shown in Appendix.

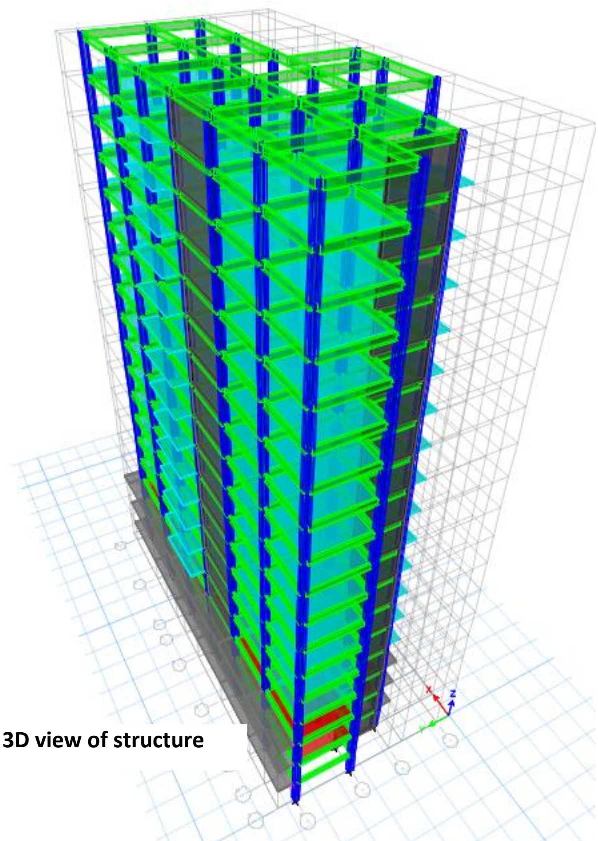

Figure3.5 3D view of structure

3.3.2. Steel Structure

According to same architectural plan as shown in Figure 3.2 and Figure 3.3, steel structural system is formed with concrete slab on corrugated steel deck. In case of steel structure with composite floor i.e. RC slab with steel deck is connected to supporting steel girder and beam by sufficient shear connectors. Shear connectors make the beam composite by resisting the horizontal shear which develops during bending.

I sections are used for columns and beams. This RC floor slab is connected with supporting steel beams or girders with the help of mechanical shear connectors. The same shear wall used on RC structure is used in order to see the effect of selection of material reinforced concrete and steel structure as shown in Figure 3.5. Floor slab is assumed as rigid in plane and acts as diaphragm to transfer lateral load horizontally the two shear walls and column.

No Bracing is used in the structure. Column joints are fully restrained. Girders and beams are capable to reach plastic strength collapse mechanism where plastic hinge rotation is necessary. Table 3-2 shows design section for steel structure. Design section for steel structure is shown in Appendix.

3.3.3. Composite Structure

For the same floor plan as shown in Figure 3.1 and Figure 3.2, composite structure is modeled as the same way as the steel structure except Composite sections are used for column. The same shear wall system is used as shown in Figure 3.4. Design section for composite structure is shown in Appendix.

3.4. Design Loads

Both gravity loads (dead load and live load) and lateral load (earthquake load) are considered to analyze the selected building for the three types of structural systems. Design loads are considered and calculated following the new revised Ethiopian building code of standard.

3.4.1. Gravity loads

Live load and dead load are gravity loads considered for the design of the building for the intended design.

3.4.1.1. Design Live Loads

Live load considered to perform design work is given in Table 3.1. Live loads are considered as per EBCS.

Table 3-1 Live Load

Function	Live load(KN/m^2)
Shop	5
Parking	2.5
Residence	2
Roof top	2

3.4.1.2. Dead Load Calculations

Self-weight of structure is considered by ETABS 2016 software. Finishing material Block work and supper dead are calculated and assigned in the software.

3.4.2. Lateral Load Calculation

Wind load is not considered in the analysis. Seismic load is calculated following Eurocode-2004 for the design of selected three types of structure.

3.5. Structural Modeling and Analysis

This section deals with; structural modeling, assigning member properties, assigning basic loads, generation of load combinations and structural analysis of the three types of structures for the intended research work.

3.5.1. Generation of Model

After selecting architectural design three dimensional structural models are generated as RC, steel and composite by using ETABS 2016 software. For RC structure solid slab is used. And for the steel and composite structure reinforced concrete slab on corrugated steel deck is formed as composite is used. To activate composite action, mechanical shear connectors have been used. RC slab on steel deck, connected with steel girder and beam by stud anchor, is generated with appropriate properties.

For all three the same lateral resisting system is used. Two shear walls oriented as shown in the Figure 3.4 is used.

3.5.2. Generation of Load Combinations

Load combinations are generated using assigned basic loads. EBCS EN 1992-2013is followed for load combinations of Composite, steel and RC structure.

3.5.3. Structural Analysis

After completion of generation of load combinations; the structural models, member properties, basic loads and load combinations are checked thoroughly. After that, dynamic analysis is performed and analysis results are preserved for structural design.

3.5.4. Properties of Structural Elements

The Following specifications of materials are used in designing of RC, steel and composite members and joints: Hot rolled section used for steel and composite structure. Grade 50 steel with Fy =345MPa and Fu = 447 MPa is used. ksi). Concrete strength used is C30 for column and beams. For slab C25 is used.

3.6. Concluding Remarks

In this chapter structural seismic analysis of the selected G+15 condominium building have been completed using three types of structures RC, steel and composite. Summary of all data for these structures is now available which has been analyzed in the next chapter.

Chapter 4
RESULT AND DISCUSSION

4.1. Introduction

Comparison, analysis and discussion have been performed using all data obtained from load calculation, structural modeling and analysis, design of the selected Composite, steel and RC types of structural system for the same building. The explained 3D building model is analyzed using modal spectrum analysis. The building models are then analyzed by the software ETABS 2016. Different parameters such as deflection, Story shear, base shear, story stiffness and Time period are studied for the models. We used soil type C and zone II from EBCS for analysis.

4.2. Analysis of Time Period

Every building has a number of natural frequencies, at which it offers minimum resistance to shaking induced by external effects (like earthquakes and wind) and internal effects (like motors fixed on it). The mode of oscillation with the smallest natural frequency (and largest natural period) is called the Fundamental Mode; the associated natural period T1 is called the Fundamental Natural Period.

The time an object takes to vibrate back and forth one complete cycle is known as Time period. It is one of the most important factors determining how a structure will respond to ground shaking. On the analysis we used 20 modes and each mode has its own time period. Here below we see the time periods of the three structures.

Table 4-1 Time Period for all modes

	Time Period(sec)				Time Period(sec)		
Mode	Composite	Steel	RCC	Mode	Composite	Steel	RCC
Mode 1	2.645	4.99	3.173	Mode 11	0.178	0.298	0.221
Mode 2	1.721	2.721	2.103	Mode 12	0.17	0.277	0.2
Mode 3	1.503	2.105	1.757	Mode 13	0.141	0.253	0.177
Mode 4	0.865	1.28	1.067	Mode 14	0.137	0.22	0.163
Mode 5	0.49	0.823	0.596	Mode 15	0.115	0.214	0.145
Mode 6	0.473	0.694	0.582	Mode 16	0.102	0.19	0.122
Mode 7	0.379	0.526	0.451	Mode 17	0.097	0.179	0.12
Mode 8	0.325	0.504	0.399	Mode 18	0.094	0.167	0.119
Mode 9	0.234	0.4	0.288	Mode 19	0.091	0.161	0.114
Mode 10	0.226	0.316	0.273	Mode 20	0.081	0.137	0.109

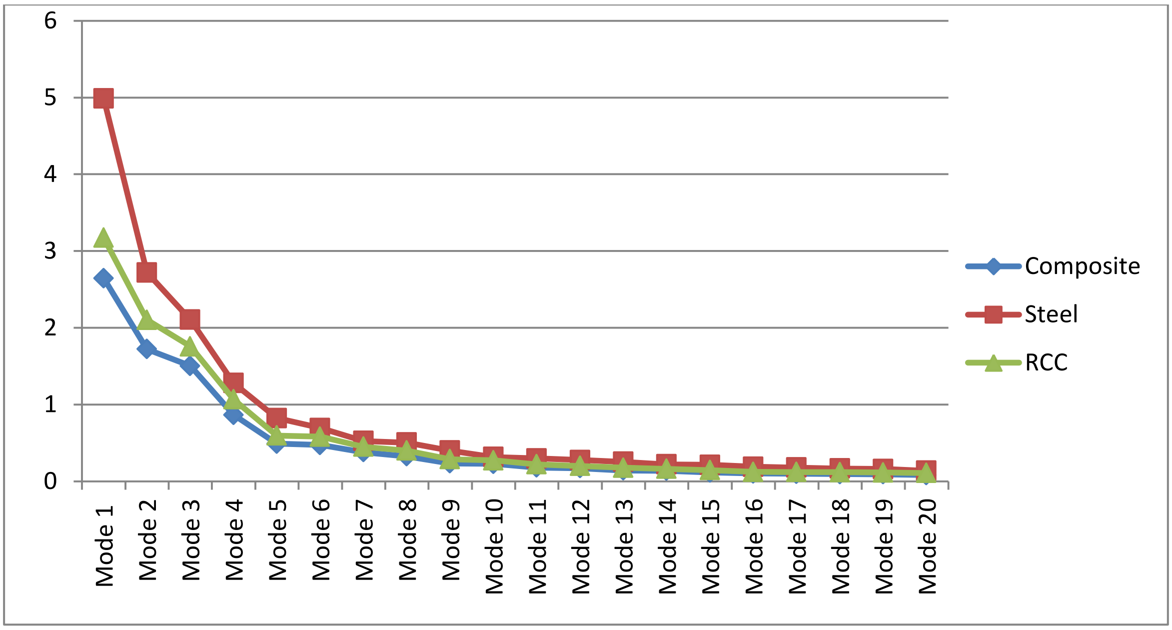

Figure 4.1 Comparison of Time Period

The fundamental period (First mode time period) of Steel structure is about 4.99 sec which is 46% and 36% higher than composite and RC structure respectively. To complete one cycle steel structure take more time because of its ductility. The first mode of vibration in composite structure is 16% lower than the RC structure.

4.3. Deflection

Displacements, the extent to which a structural element moves or bends under pressure is the main serviceability concern in the structures. Lateral displacements that occur during earthquakes should be limited to prevent distress in structural members and architectural components.

The value of maximum displacement is a direct and efficient measure used to quantify the overall displacement response of a building. However, the value of roof displacement provides no direct information about localized deformation within a structure.

4.3.1. X-Direction Deflection

Table 4-2 X-direction deflection

	X-Direction Defection (mm)		
Location	Composite	Steel	RCC

Base	0	0.00	0
Basement 2	4.72748117	8.17	6.56
Basement 1	7.93549006	12.50	10.202
Story1	10.6947691	22.34	14.748
Story2	13.486548	33.98	18.201
Story3	16.400207	45.84	21.834
Story4	19.3372149	57.01	25.61
Story5	22.2424494	67.16	29.387
Story6	25.0766234	75.17	33.114
Story7	27.8091779	78.03	36.997
Story8	30.4160357	81.15	40.736
Story9	32.8791572	84.51	44.287
Story10	35.1860887	88.01	47.621
Story11	37.3281451	91.57	50.718
Story12	39.2980698	95.12	53.564
Story13	41.0892209	98.59	56.147
Story14	42.7028483	101.93	58.466
Story15	44.1367242	105.13	60.533
Roof Top	42.3460533	98.05	57.734

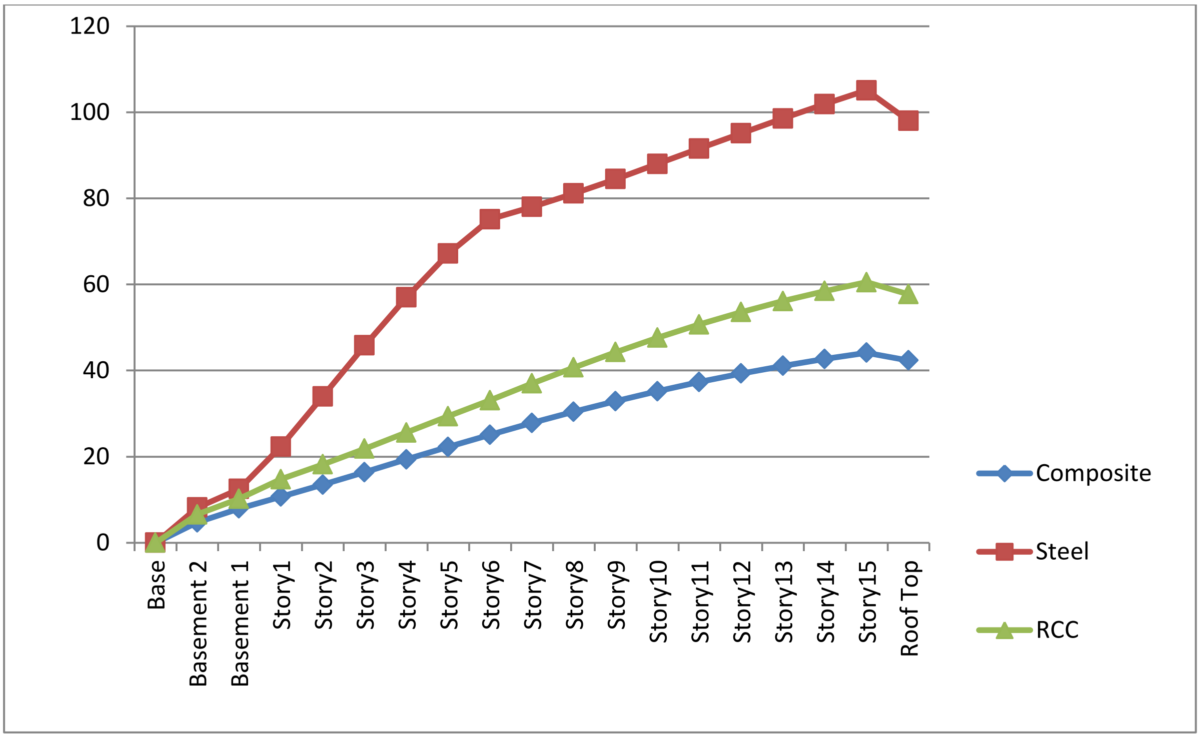

Figure 4.2 comparison X-direction deflection

The maximum roof displacement for the X-direction for steel structure is 41% higher than RC structure and 56% higher than Composite structure. Steel structure is more ductile so this result is expected. The composite structure shows a 26% reduction compared to RC structure. This means the composite structure is stiffer than the two structures in this direction.

4.3.2. Y-Direction Deflection

Table 4-3 Y-direction deflection

	Y-Direction Deflection (mm)		
Location	Composite	Steel	RCC
Base	0	0.00	0
Basement 2	9.5156798	16.78	13.264
Basement 1	15.748636	26.19	21.68
Story1	20.711719	48.91	29.301
Story2	25.402361	76.24	35.495

Story3	30.081561	104.48	41.77
Story4	34.617293	131.39	48.107
Story5	38.957116	155.93	54.259
Story6	43.073646	175.38	60.167
Story7	46.947247	182.01	66.213
Story8	50.561264	188.11	71.889
Story9	53.900332	193.89	77.136
Story10	56.948429	199.28	81.922
Story11	59.686904	204.26	86.215
Story12	62.094139	208.80	89.981
Story13	64.146893	212.87	93.186
Story14	65.824769	216.45	95.805
Story15	67.121971	219.52	97.832
Roof Top	65.462916	214.24	95.616

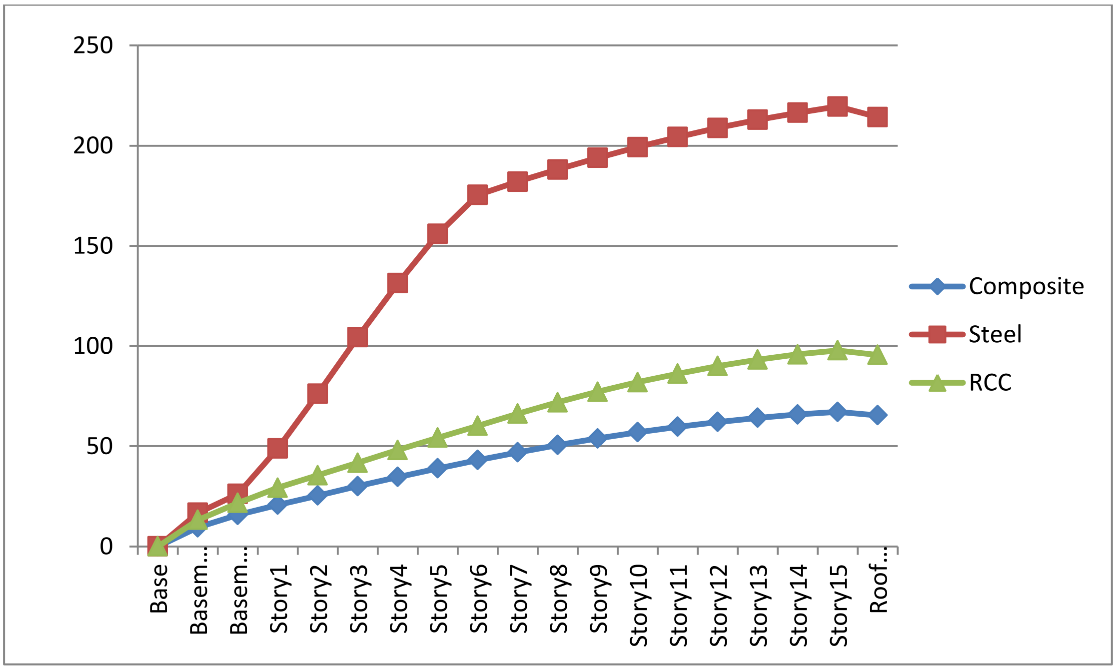

Figure 4.3 Comparison of Y-direction deflection

The maximum roof displacement for the Y-direction for steel structure is 55% higher than RC structure and 69% higher than that of Composite structure. Steel structure is more ductile so this result is expected. The composite structure shows a 31% reduction compared to RC structure. In this direction also the composite structure is stiff out of the three.

4.4. Story Stiffness

Stiffness is a measure of how much force is required to displace a building by a certain amount. If a large force is required to displace a building is said to be stiff. Large stiffness can be advantageous with respect to earthquake damage because it can limit the deformation demands on a building. The lateral stiffness of the three structured are analyzed below.

4.4.1. X-Direction

Table 4-4 Story Stiffness in the X-Direction

Story	Composite	Steel	RC
Roof Top	148273.351	34973.099	142139.853
Story15	351556.349	98090.234	263880.417
Story14	471390.782	133298.013	341904.936
Story13	519133.444	144984.9	366945.856
Story12	532077.117	147276.415	370653.823
Story11	537111.92	151789.059	374544.125
Story10	547251.311	162769.317	387511.164
Story9	564548.325	178597.374	407535.445
Story8	585959.275	197136.724	428262.575
Story7	607567.351	220617	447442.414
Story6	631002.376	171703.441	488531.608
Story5	661690.922	152912.337	513420.748
Story4	704900.03	149340.405	548704.581
Story3	768014.037	152547.615	609570.05
Story2	870797.843	171511.74	702973.47
Story1	1016221.011	230645.983	859382.758
Basement1	1071311.523	519399.077	950304.074
Basement2	942445.877	376385.38	635938.413
Base	0	0	0

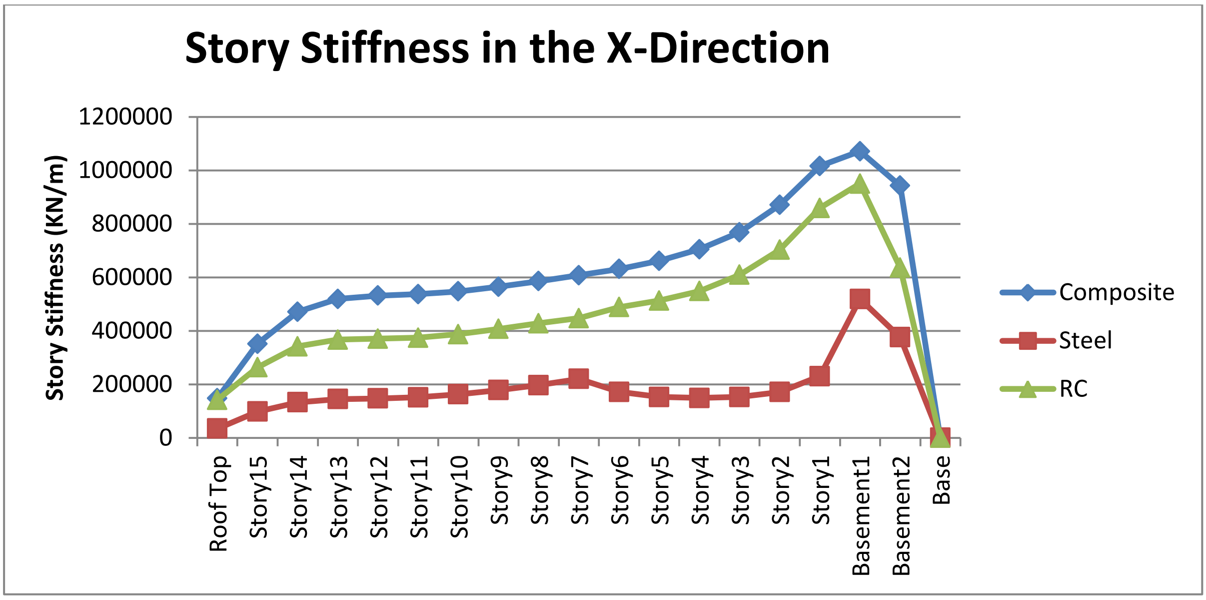

Figure 4.4 Comparison of Story Stiffness in the X-Direction

The maximum Story stiffness for the X-direction for composite structure is 51% higher than steel structure and 11% higher than that of RC structure. Steel structure is more ductile so this result is expected. The RC structure shows a 45% increase compared to Steel structure.

4.4.2. Y-Direction

Table 4-5 Story Stiffness in the Y-Direction

Story	Composite	Steel	RC
Roof Top	88590.674	42239.259	85635.487
Story15	236746.154	116866.28	181850.86
Story14	306055.331	145582.5	225615.41
Story13	333190.822	146841.52	234418.92
Story12	327553.507	140679.29	227170.06
Story11	325691.467	140518.12	226885.23
Story10	330015.626	147195.47	233288.38
Story9	336692.994	153768.32	240561.75
Story8	343356.736	157918.59	245915.33
Story7	347630.102	157016.93	250119.18
Story6	350969.705	73288.659	269321.9
Story5	355925.048	63371.916	274901.53
Story4	365176.42	62339.155	284186

Story3	382940.827	63594.264	307388.46
Story2	417791.587	69804.737	343051.76
Story1	458686.932	90099.208	376292.86
Basement1	437734.921	221770.97	350999.74
Basement2	343781.471	149103.47	253012.48
Base	0	0	0

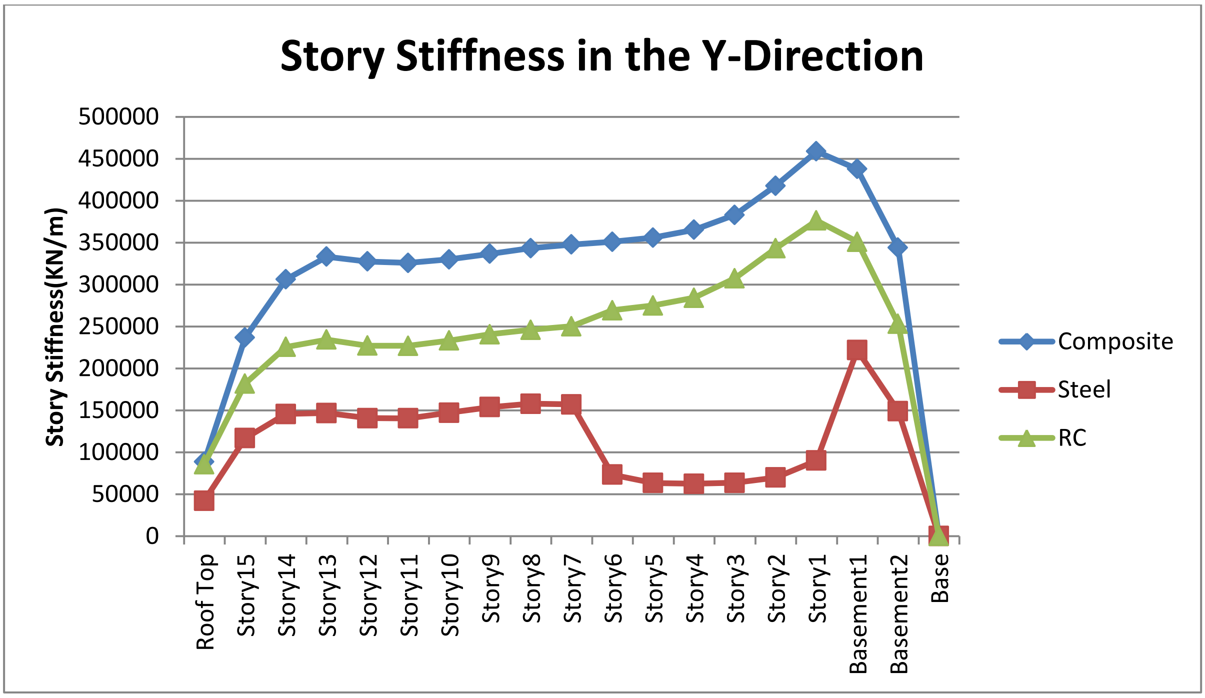

Figure 4.5 Comparison of Story Stiffness in the Y-Direction

The maximum Story stiffness for the Y-direction for composite structure is 49% higher than steel structure and 19% higher than that of RC structure. Steel structure is more ductile so this result is expected. The RC structure shows a 36% increase compared to Steel structure.

4.5. Cost Analysis

The materials volume obtained from the output of the design and current material prices are used for the cost analysis in order to identify cost of steel, RC and composite structures. The cost of structure less foundation for the three structures is summarized in table 4.7. For cost analysis, current values of construction costs including overhead cost are used for the analysis. Table 4.6 below shows the unit rate for different items. Note that prices of materials fluctuates in time, this obtained result will also change accordingly. Therefore; this result works only for limited period of time.

Table 4-6 Unit Rate of Material

No.	Material	Unit	Unit Rate
1	Reinforcing Bar	Kg	40
2	Concrete	M^3	3100
3	Formwork	M^2	280
4	Structural Steel	Kg	64

Table 4-7 Cost of steel, RC and Composite structures

No.	Material	Unit	Total Cost
1	Steel Structure	Birr	16,823,250
2	RC Structure	Birr	21,889,530
3	Composite Structure	Birr	20,750,560

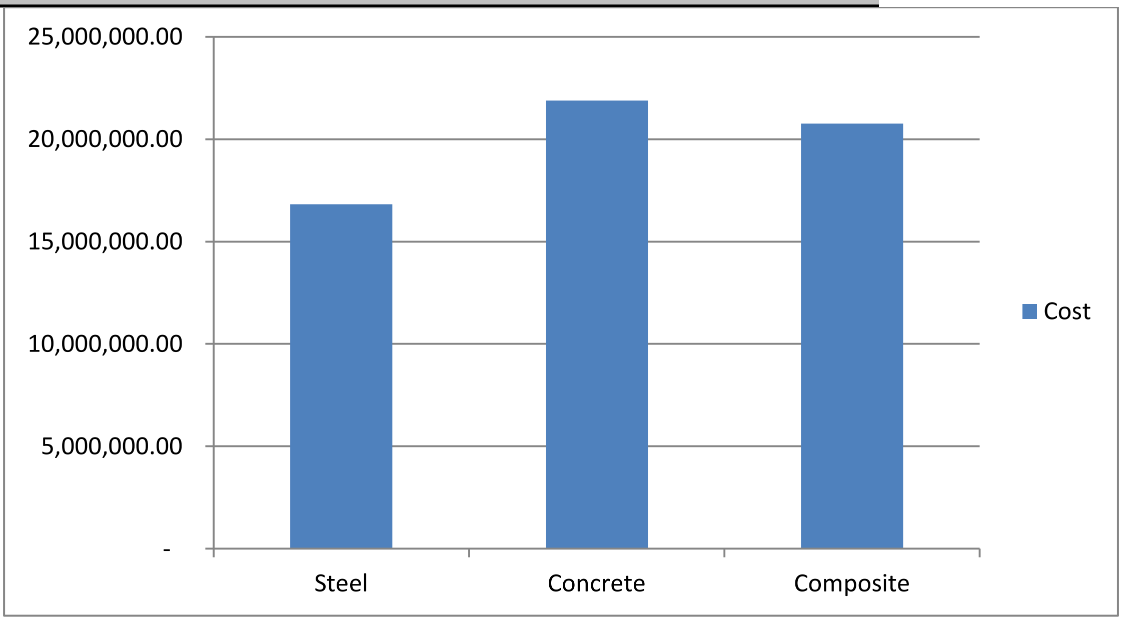

Figure 4.6 Cost Comparison of RC, Steel and composite structures

Cost of structural element of the G+15 building for the three structures is as seen in table4.7. Cost of steel structure is less as compared to steel and composite structure. Cost of steel structure is 22% lower than RC structure and 18% lower than composite structure. And cost of composite structure is 5% lower than RC structure.

4.6. Base Shear

Seismic forces accumulate downward in a building. Seismic forces in the building are greatest at the base of the building. The seismic force at base of the building is called the *base shear.* Earthquakes often damage buildings at this level. In a multi-storey building all vibration modes of the building contribute to the base shear as shown below.

Table 4-8 Base shear for rspx and rspy

Direction	composite	steel	RCC
rsp_x	2303.247	1513.161	2276.581
rsp_y	1693.033	1258.84	1776.9664

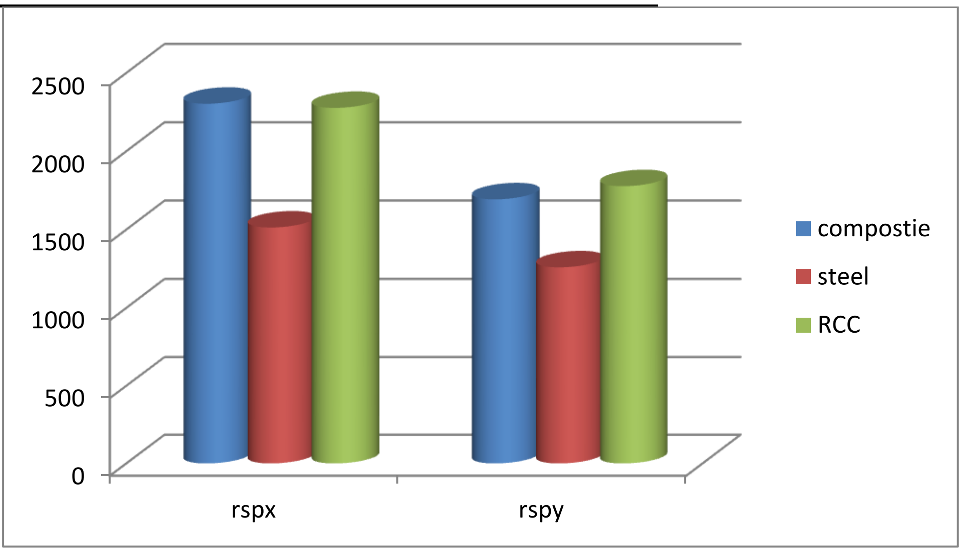

Figure 4.7 Comparison of Base shear due to rspx and rspy

It is evident that, the steel structure has low base shear as expected. But composite structure from chart above for earthquake response in the X-direction base shear shows 1.1% increase when compared to the RC structure. For earthquake response in the y-direction the base shear in composite structure shows 4.8% decrease when compared RC structure.

4.7. Story Shear

4.7.1. Composite Structure

Table 4-9 Story shear for composite structure in X & Y direction

Story	X-Dir	Y-Dir	Story	X-Dir	Y-Dir

	kN	kN		kN	kN
Roof Top	166.8801	125.037	Story6	1585.7433	1180.6984
	166.8801	125.037		1585.7433	1180.6984
Story15	590.2463	411.4558	Story5	1663.4339	1227.9231
	590.2463	411.4558		1663.4339	1227.9231
Story14	868.1686	591.2901	Story4	1748.3497	1280.5416
	868.1686	591.2901		1748.3497	1280.5416
Story13	1029.4754	695.912	Story3	1843.3528	1346.1933
	1029.4754	695.912		1843.3528	1346.1933
Story12	1123.2214	768.9777	Story2	1953.6191	1428.0627
	1123.2214	768.9777		1953.6191	1428.0627
Story11	1191.7206	842.1415	Story1	2117.5954	1546.7102
	1191.7206	842.1415		2117.5954	1546.7102
Story10	1260.6369	923.2328	Basement 1	2265.3823	1660.6393
	1260.6369	923.2328		2265.3823	1660.6393
Story9	1341.3049	1003.3324	Basement 2	2303.2468	1693.033
	1341.3049	1003.3324		2303.2468	1693.033
Story8	1428.4538	1073.7444	Base	0	0
	1428.4538	1073.7444		0	0
Story7	1510.1331	1131.7273			
	1510.1331	1131.7273			

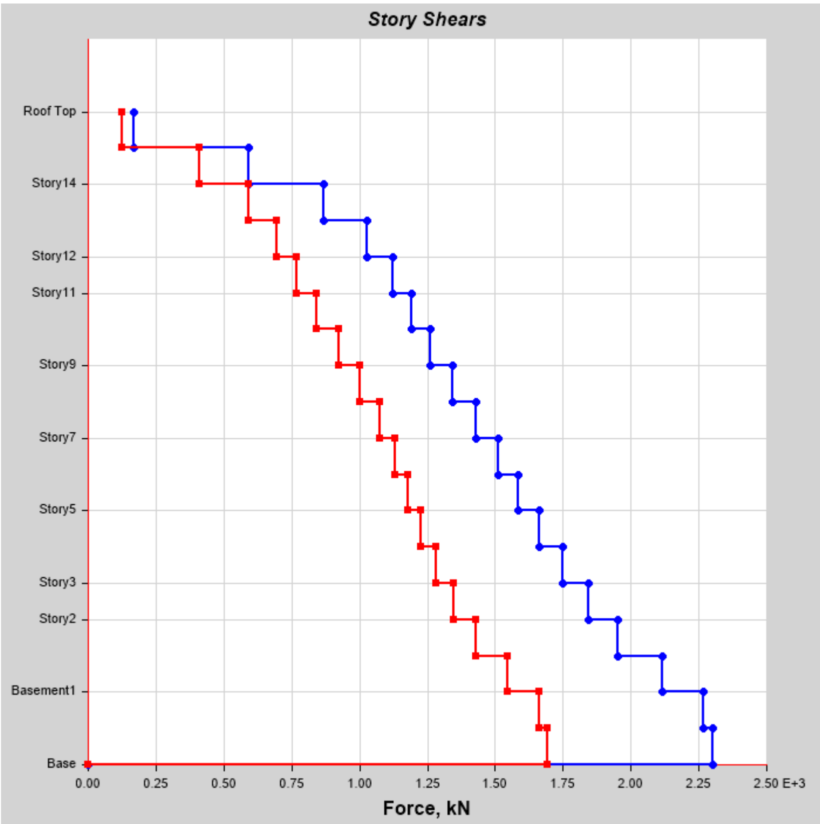

Figure 4.8 Composite structure story shear in the Y and X direction

4.7.2. Steel Structure

Table 4-10 Story shear for steel structure in X & Y direction

Story	X-Dir	Y-Dir	Story	X-Dir	Y-Dir
	kN	**kN**		**kN**	**kN**
Roof Top	138.7806	97.2006	Story6	979.5234	884.0672
	138.7806	97.2006		979.5234	884.0672
Story15	403.9667	343.101	Story5	1025.1106	921.4752
	403.9667	343.101		1025.1106	921.4752
Story14	568.095	487.1641	Story4	1062.4158	971.0994
	568.095	487.1641		1062.4158	971.0994
Story13	636.595	547.3679	Story3	1120.251	1023.8284
	636.595	547.3679		1120.251	1023.8284
Story12	661.059	571.5772	Story2	1215.3812	1079.5661
	661.059	571.5772		1215.3812	1079.5661
Story11	690.0166	611.936	Story1	1372.5685	1157.636
	690.0166	611.936		1372.5685	1157.636
Story10	742.1375	679.1145	Basement 1	1493.3373	1236.7662
	742.1375	679.1145		1493.3373	1236.7662
Story9	808.1494	746.4415	Basement 2	1513.1608	1258.84
	808.1494	746.4415		1513.1608	1258.84
Story8	872.9226	799.1942	Base	0	0
	872.9226	799.1942		0	0
Story7	930.1	841.8784			
	930.1	841.8784			

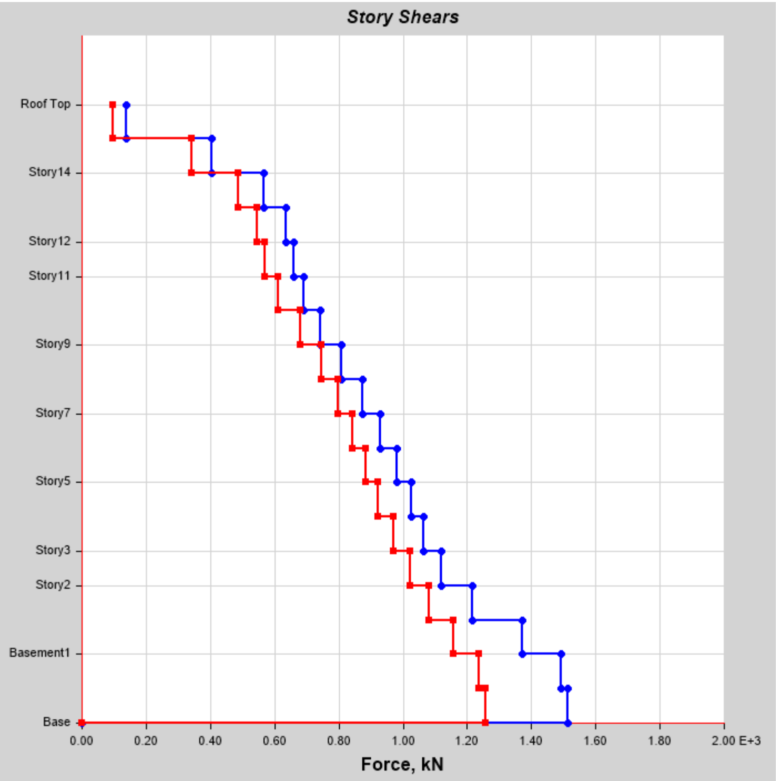

Figure 4.9 Steel structure story shear in the Y and X direction

4.7.3. RC Structure

Table 4-11 Story shear for RC structure in X & Y direction

Story	X-Dir	Y-Dir	Story	X-Dir	Y-Dir
	kN	**kN**		**kN**	**kN**
Roof Top	218.604	174.6024	Story6	1545.5462	1251.313
	218.604	174.6024		1545.5462	1251.313
Story15	619.9059	454.1914	Story5	1611.8548	1300.9276
	619.9059	454.1914		1611.8548	1300.9276
Story14	868.792	618.4988	Story4	1682.1393	1354.0138
	868.792	618.4988		1682.1393	1354.0138
Story13	996.2701	708.9664	Story3	1768.8729	1423.0893
	996.2701	708.9664		1768.8729	1423.0893
Story12	1062.524	779.7115	Story2	1890.944	1514.0464
	1062.524	779.7115		1890.944	1514.0464
Story11	1122.1915	863.7212	Story1	2077.6158	1637.201
	1122.1915	863.7212		2077.6158	1637.201
Story10	1203.8186	959.8667	Basement 1	2232.2245	1744.1104
	1203.8186	959.8667		2232.2245	1744.1104
Story9	1303.8291	1053.3037	Basement 2	2276.581	1776.9664
	1303.8291	1053.3037		2276.581	1776.9664
Story8	1399.7162	1132.947	Base	0	0
	1399.7162	1132.947		0	0
Story7	1478.2959	1196.8571			
	1478.2959	1196.8571			

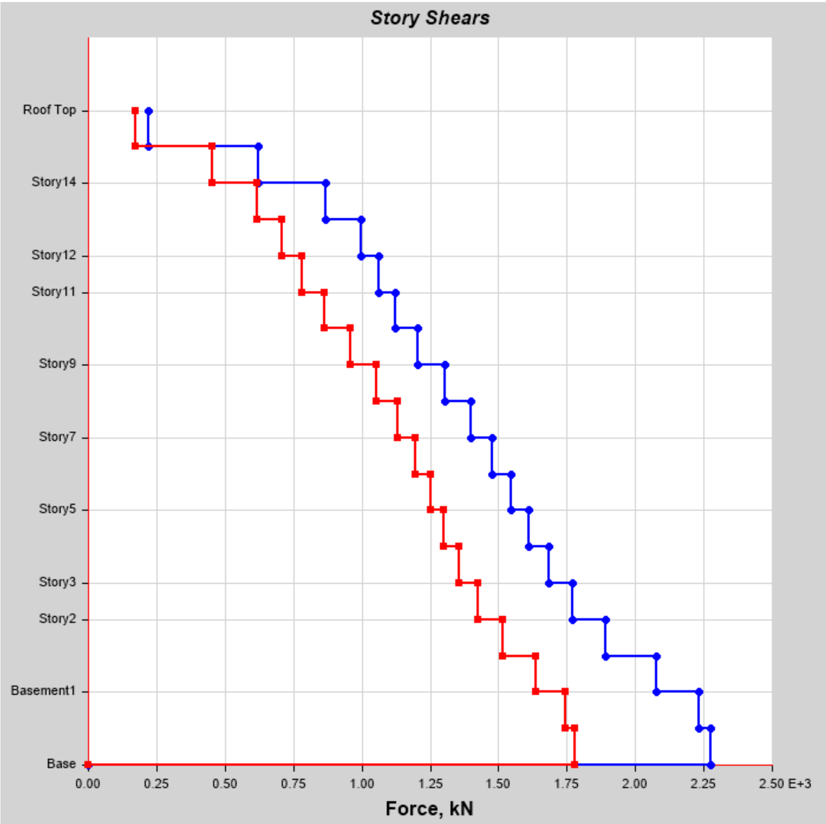

Figure 4.10 RC structure story shear in the Y and X direction

4.8. Axial Load

Axial load is the vertical load from the structure transferred to the foundation. Comparison of maximum load is shown below.

Table 4-12 Maximum axial load

Type of structure	FY(KN)
Composite	127336.8
Steel	118159.7
RC	144461.1

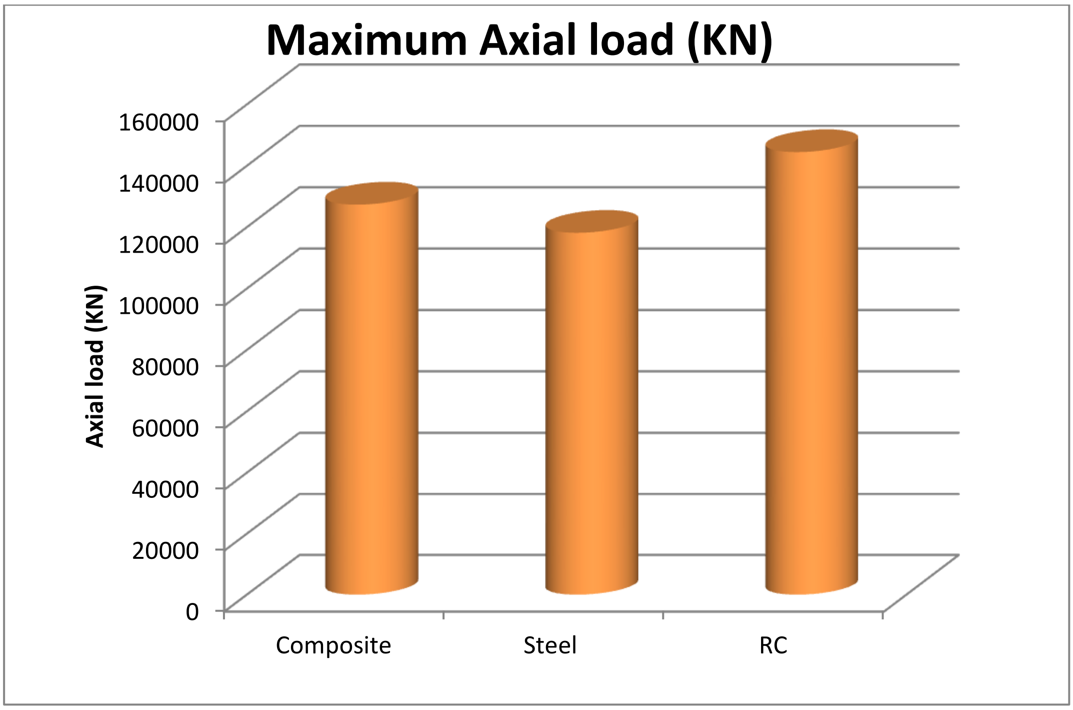

Figure 4.11 Comparison of maximum axial load

The maximum axial load for steel structure is 7% lower than composite structure and 18% lower than that of RC structure. Steel structure is lighter than the two structures as expected. The composite structure shows 11% reduction compared to RC structure.

4.9. Mode Shape

Mode shapes describe the configuration into which a structure will naturally displace. Lateral displacement patterns are of primary concern. Mode shapes of low-order expression tend to provide the greatest contribution to structural response. As the order increase, mode shapes contribute less and less. It is reasonable to truncate analysis when the number of mode shapes is sufficient. In the analysis we used twenty modes. The mass participation ratio for the selected 20 mode of structure is more than 90% for all three types of structures so 20 modes selected are enough. Here below the mass participation ratio of the three structures are discussed.

4.9.1. Composite Structure

The mass participation ratio shows the modes selected are more than enough. More than 95% of the mass of the composite structure is participated in the dynamic analysis in both directions. The table below shows the sum of mass participation ratio of composite structure in the X and Y direction.

Table 4-13 Modal Participating Mass Ratios of Composite Structure

Case	Mode	Period sec	UX	UY	UZ	Sum UX	Sum UY	Sum UZ
Modal	1	2.645	0.057	0.5564	0	0.057	0.5564	0
Modal	2	1.721	0.407	0.1824	0	0.464	0.7388	0
Modal	3	1.503	0.263	0.0549	0	0.727	0.7937	0
Modal	4	0.865	0.0058	0.07	0	0.7328	0.8638	0
Modal	5	0.49	0.0215	0.0005	0	0.7544	0.8642	0
Modal	6	0.473	0.0595	0.0562	0	0.8139	0.9205	0
Modal	7	0.379	0.0663	0.0139	0	0.8802	0.9344	0
Modal	8	0.325	0.0007	0.0042	0	0.8809	0.9386	0
Modal	9	0.234	2.383E-05	0.0024	0	0.8809	0.941	0
Modal	10	0.226	0.0345	0.0183	0	0.9154	0.9593	0
Modal	11	0.178	0.0001	0.0011	0	0.9154	0.9605	0
Modal	12	0.17	0.0286	0.0054	0	0.9441	0.9659	0
Modal	13	0.141	0.0003	0.0005	0	0.9444	0.9664	0
Modal	14	0.137	0.0148	0.0101	0	0.9592	0.9766	0
Modal	15	0.115	0.0001	0.0004	0	0.9593	0.977	0
Modal	16	0.102	0.0148	0.0018	0	0.9741	0.9788	0
Modal	17	0.097	1.245E-05	0.0012	0	0.9741	0.98	0
Modal	18	0.094	0.0031	0.0048	0	0.9773	0.9848	0
Modal	19	0.091	0.0004	0.0004	0	0.9777	0.9852	0
Modal	20	0.081	3.794E-05	0.0003	0	0.9777	0.9855	0

The above table is summarized below.

Table 4-14 Modal Load Participation Ratio for Composite Structure

Case	Item Type	Item	Static %	Dynamic %
Modal	Acceleration	UX	100	97.77
Modal	Acceleration	UY	100	98.55
Modal	Acceleration	UZ	0	0

4.9.2. Steel Structure

More than 95% of the mass of the steel structure is participated in the dynamic analysis in both directions. The table below shows the sum of mass participation ratio of steel structure in the X and Y direction.

Table 4-15 Modal Participating Mass Ratios of Steel Structure

Case	Mode	Period sec	UX	UY	UZ	Sum UX	Sum UY	Sum UZ
Modal	1	4.99	0.0297	0.5644	0	0.0297	0.5644	0
Modal	2	2.721	0.4948	0.102	0	0.5246	0.6664	0
Modal	3	2.105	0.1351	0.1158	0	0.6596	0.7822	0
Modal	4	1.28	0.0279	0.0426	0	0.6875	0.8248	0
Modal	5	0.823	0.0018	0.0392	0	0.6893	0.864	0
Modal	6	0.694	0.1371	0.0215	0	0.8264	0.8855	0
Modal	7	0.526	0.0001	0.0347	0	0.8265	0.9202	0
Modal	8	0.504	0.0404	0.0132	0	0.867	0.9334	0
Modal	9	0.4	0.0062	0.0006	0	0.8731	0.9339	0
Modal	10	0.316	0.0003	0.0044	0	0.8734	0.9384	0
Modal	11	0.298	0.0365	0.0128	0	0.9098	0.9512	0
Modal	12	0.277	0.0065	0.0031	0	0.9163	0.9543	0
Modal	13	0.253	4.251E-05	0.0007	0	0.9164	0.9551	0
Modal	14	0.22	0.0003	0.0014	0	0.9166	0.9564	0
Modal	15	0.214	0.0149	0.01	0	0.9315	0.9664	0
Modal	16	0.19	0.0071	0.0006	0	0.9386	0.967	0
Modal	17	0.179	0.0022	0.0003	0	0.9408	0.9673	0
Modal	18	0.167	0.0151	0.0082	0	0.9559	0.9755	0
Modal	19	0.161	0.0006	0.0001	0	0.9565	0.9756	0
Modal	20	0.137	6.964E-06	1.036E-05	0	0.9565	0.9756	0

The above table of mass participation ratio is summarized below.

Table 4-16 Modal Load Participation Ratio of Steel Structure

Case	Item Type	Item	Static %	Dynamic %
Modal	Acceleration	UX	99.99	95.65
Modal	Acceleration	UY	100	97.56
Modal	Acceleration	UZ	0	0

4.9.3. RC Structure

More than 95% of the mass of the RC structure is participated in the dynamic analysis in both directions. The table below shows the sum of mass participation ratio of RC structure in the X and Y direction.

Table 4-17 Modal Participating Mass Ratios of RC Structure

Case	Mode	Period sec	UX	UY	UZ	Sum UX	Sum UY	Sum UZ
Modal	1	3.173	0.0636	0.5603	0	0.0636	0.5603	0
Modal	2	2.103	0.3906	0.1846	0	0.4541	0.7449	0
Modal	3	1.757	0.2615	0.0442	0	0.7156	0.7891	0
Modal	4	1.067	0.0084	0.0731	0	0.724	0.8622	0
Modal	5	0.596	0.0223	0.0001	0	0.7464	0.8623	0
Modal	6	0.582	0.0638	0.0581	0	0.8102	0.9203	0
Modal	7	0.451	0.064	0.0144	0	0.8742	0.9347	0
Modal	8	0.399	0.0004	0.0043	0	0.8746	0.939	0
Modal	9	0.288	0.0002	0.0016	0	0.8748	0.9406	0
Modal	10	0.273	0.0372	0.0194	0	0.912	0.96	0
Modal	11	0.221	1.03E-05	0.0011	0	0.912	0.9611	0
Modal	12	0.2	0.0293	0.006	0	0.9413	0.967	0
Modal	13	0.177	0.0001	0.0007	0	0.9414	0.9678	0
Modal	14	0.163	0.0164	0.0099	0	0.9578	0.9777	0
Modal	15	0.145	4.016E-05	0.0005	0	0.9579	0.9782	0
Modal	16	0.122	0.0004	0.0004	0	0.9583	0.9786	0
Modal	17	0.12	0.0096	0.0029	0	0.9679	0.9815	0
Modal	18	0.119	0.004	0.0004	0	0.972	0.982	0
Modal	19	0.114	0.004	0.0026	0	0.9759	0.9845	0
Modal	20	0.109	0.0003	8.591E-06	0	0.9762	0.9846	0

The above table of mass participation ratio is summarized below

Table 4-18 Modal Load Participation Ratio of RC Structure

Case	Item Type	Item	Static %	Dynamic %
Modal	Acceleration	UX	100	97.62
Modal	Acceleration	UY	100	98.46
Modal	Acceleration	UZ	0	0

As seen in the three structures the mass contribution gets lower and lower as we go to the higher modes. If the mass contribution reached more than 85% number of selected modes can be sufficient enough to continue the analysis. In our case the twenty modes contribute more than 95% so number of modes is sufficient. Here below mode shapes of lower modes is shown side by side for the three structures.

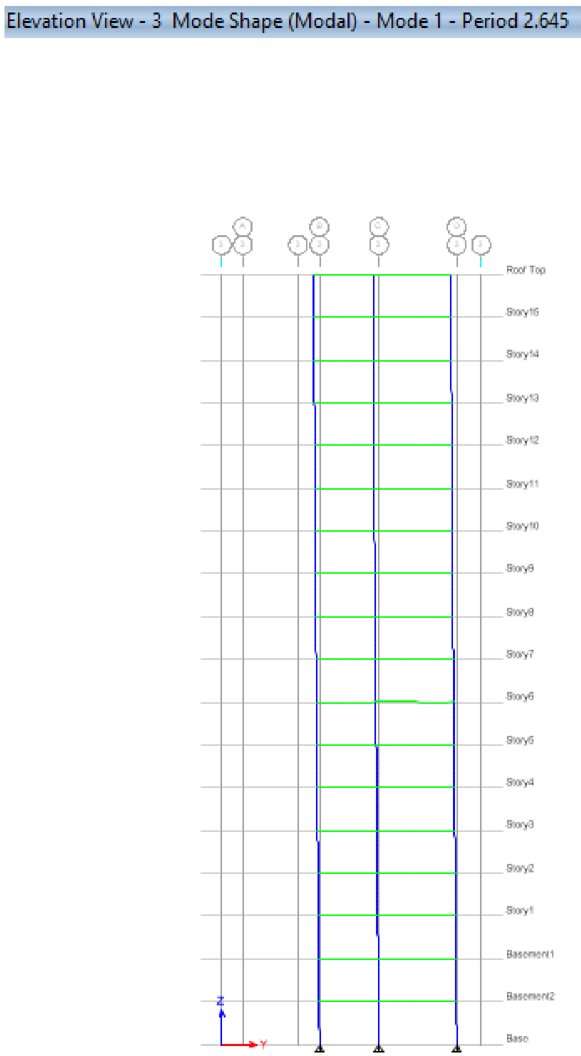

Figure 4.12 Composite Structure Mode shape 1 on axis 3

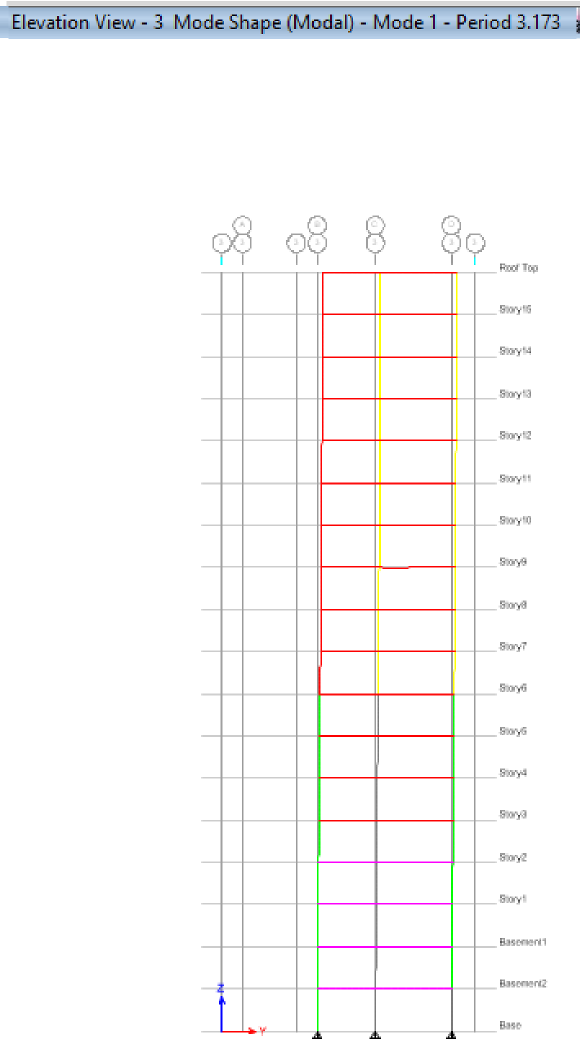

Figure 4.13 RC Structure Mode Shape1 on axis 3

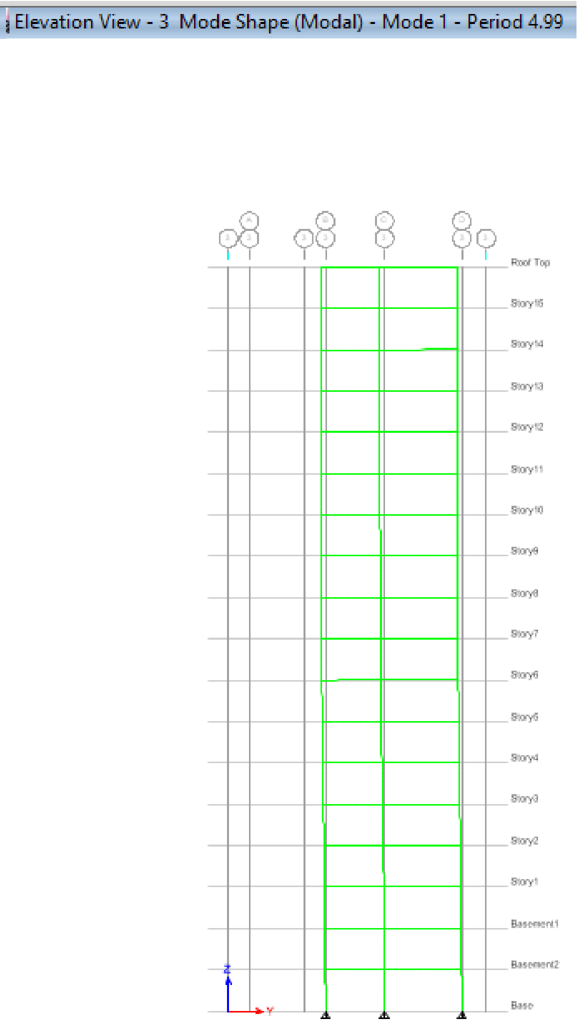

Figure 4.14 Steel Structure Mode Shape1 on axis 3

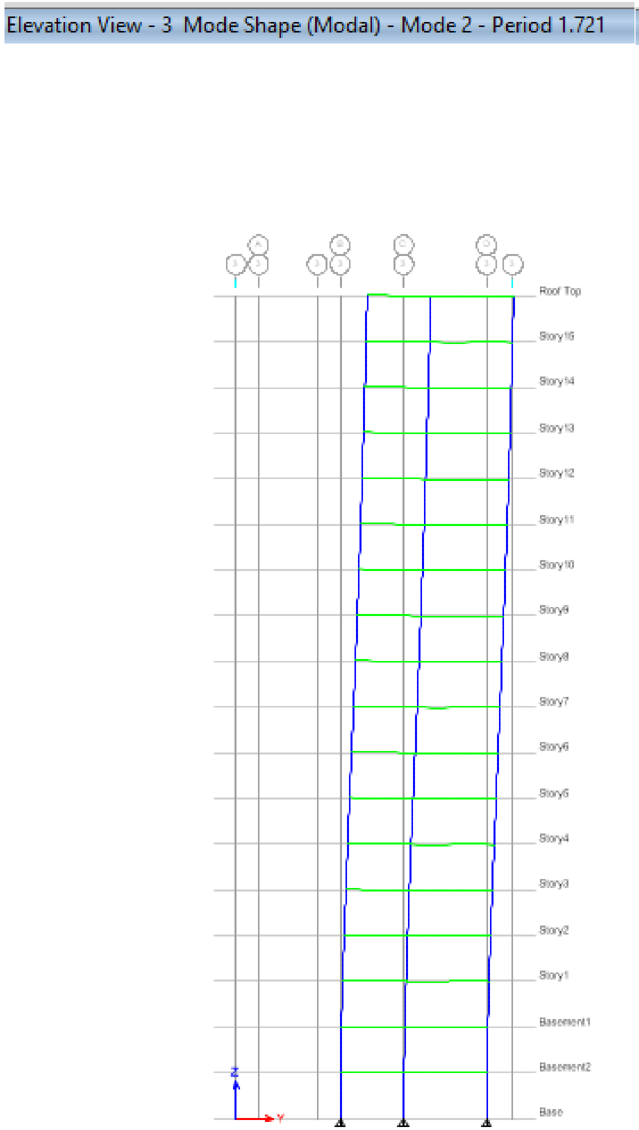

Figure 4.17 Composite Structure Mode Shape2 on axis 3

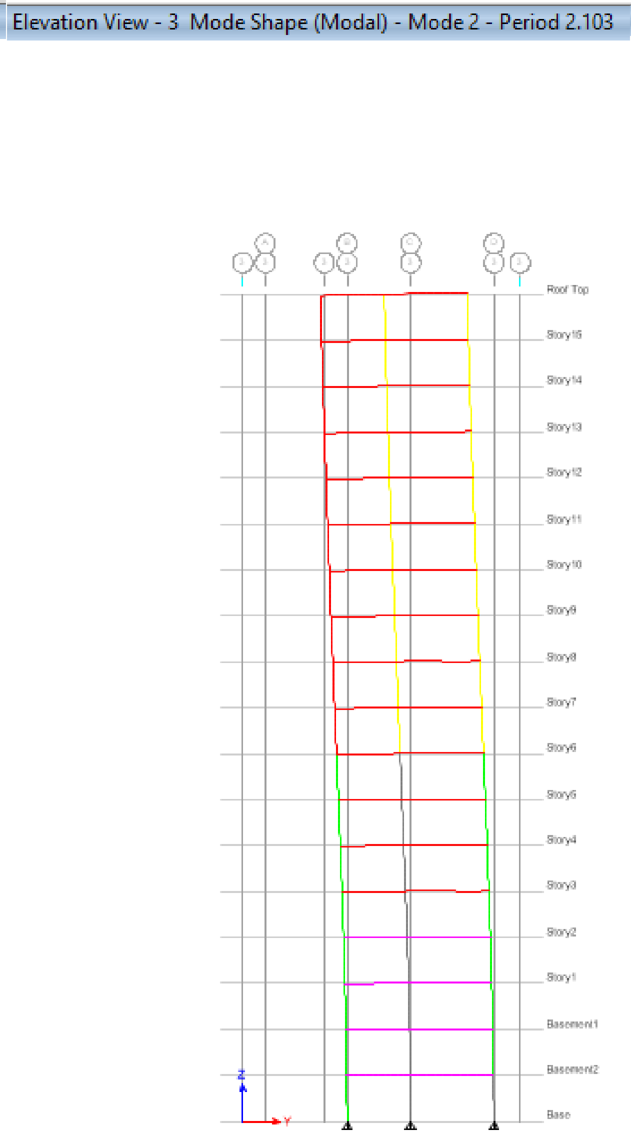

Figure 4.15 RCC Structure Mode Shape2 on axis 3

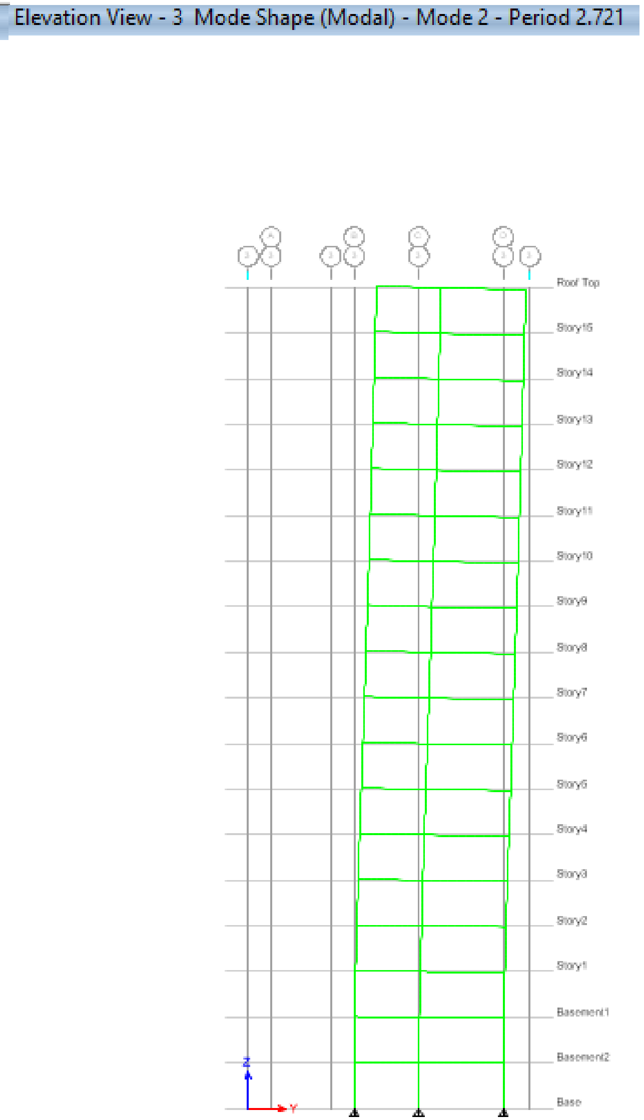

Figure 4.16 Steel Structure Mode Shape2 on axis 3

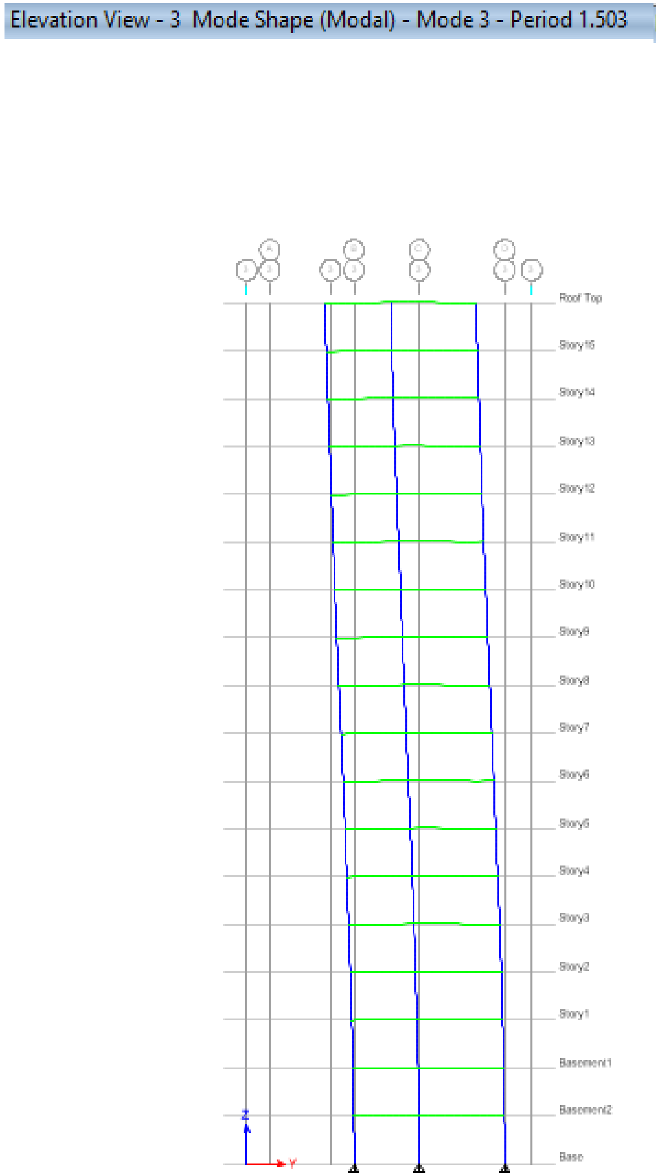

Figure 4.18 Composite Structure Mode Shape3 on axis 3

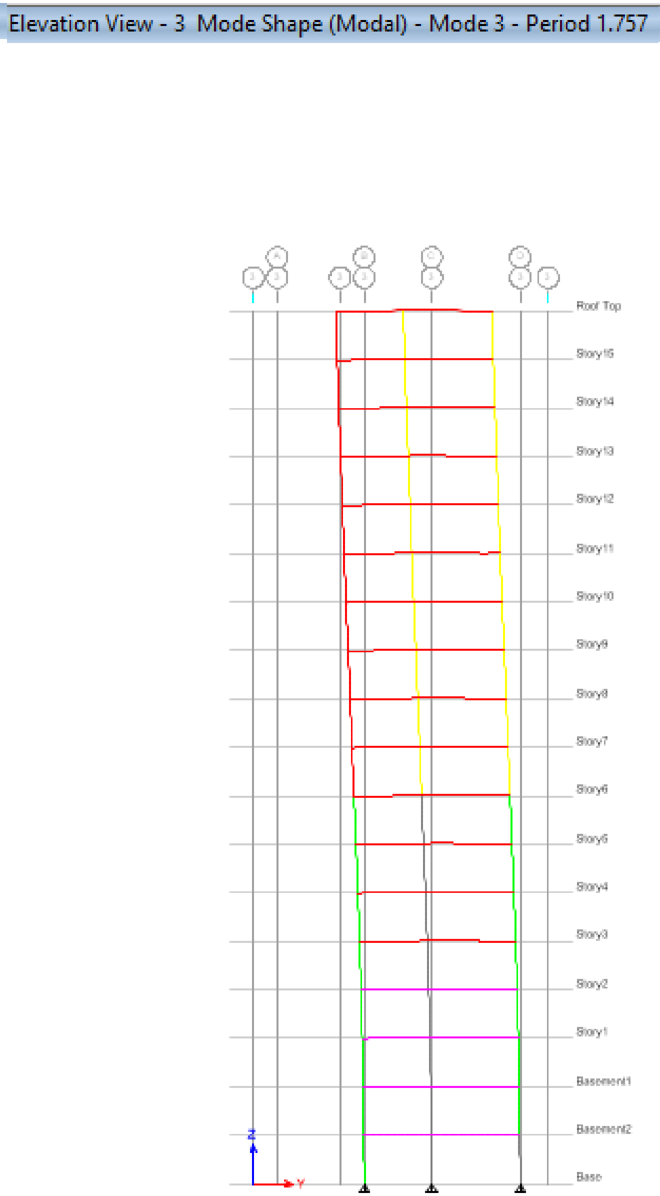

Figure 4.20 RCC Structure Mode Shape3 on axis 3

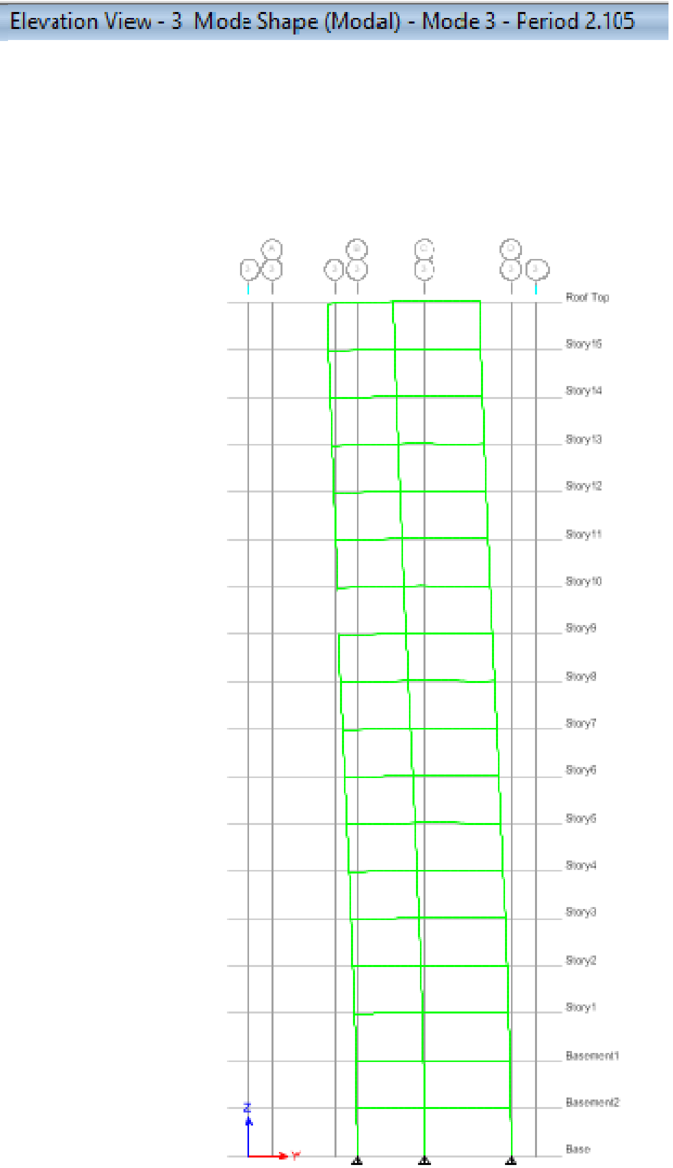

Figure 4.19 Steel Structure Mode Shape3 on axis 3

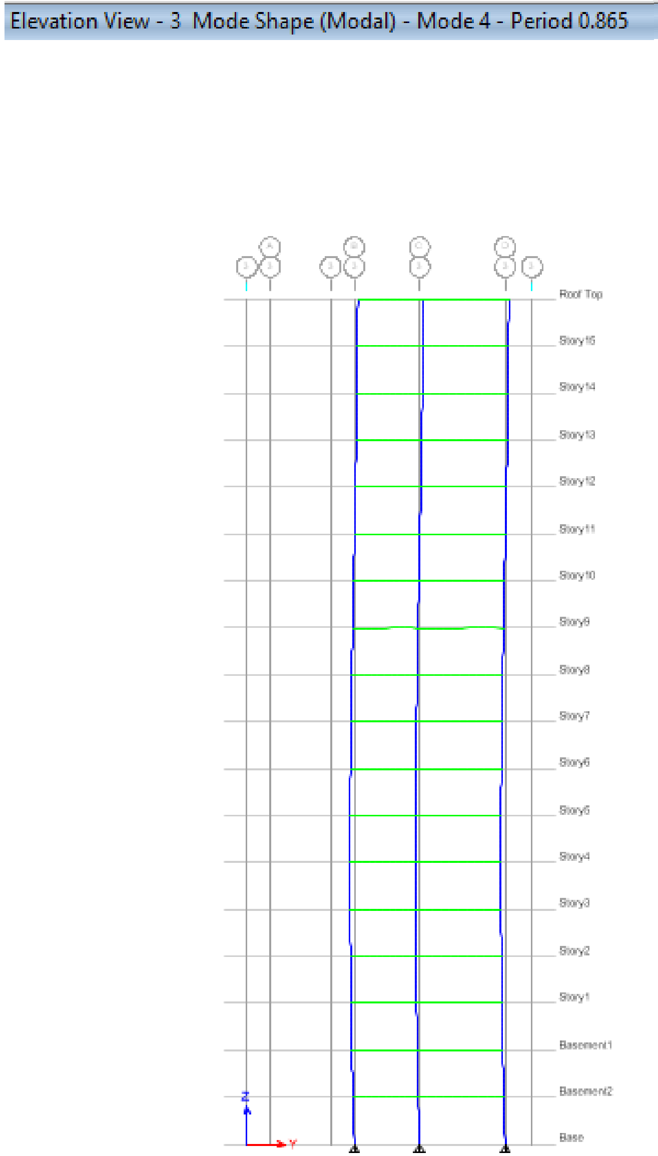

Figure 4.23 Composite Structure Mode Shape4 on axis 3

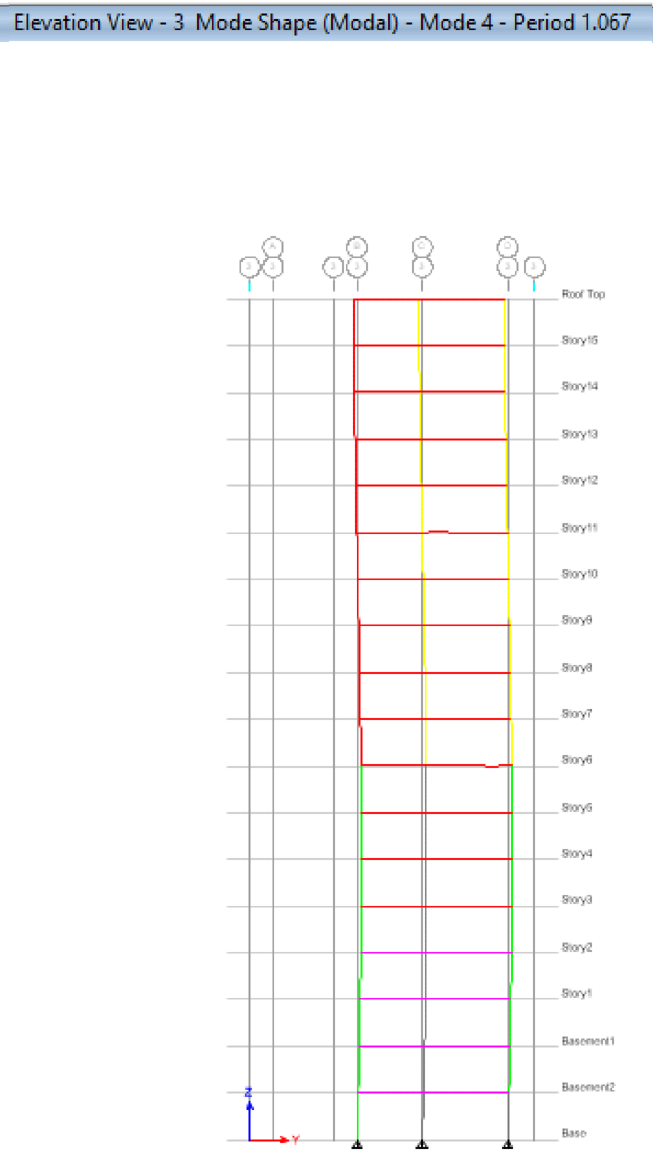

Figure 4.22 RCC Structure Mode Shape4 on axis 3

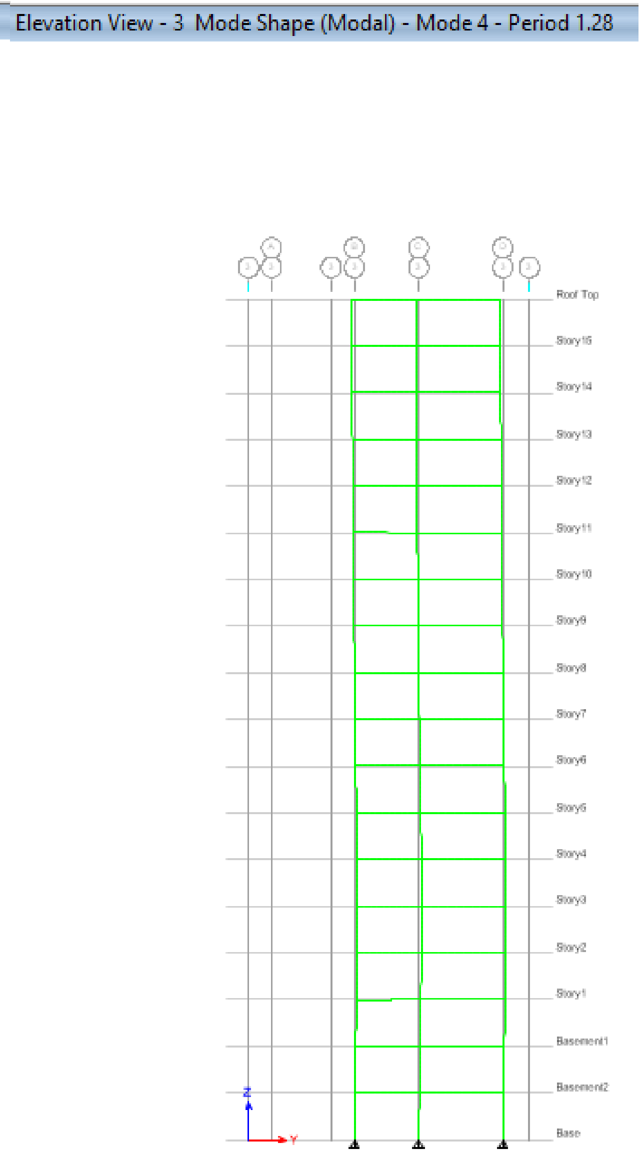

Figure 4.21 Steel Structure Mode Shape4 on axis 3

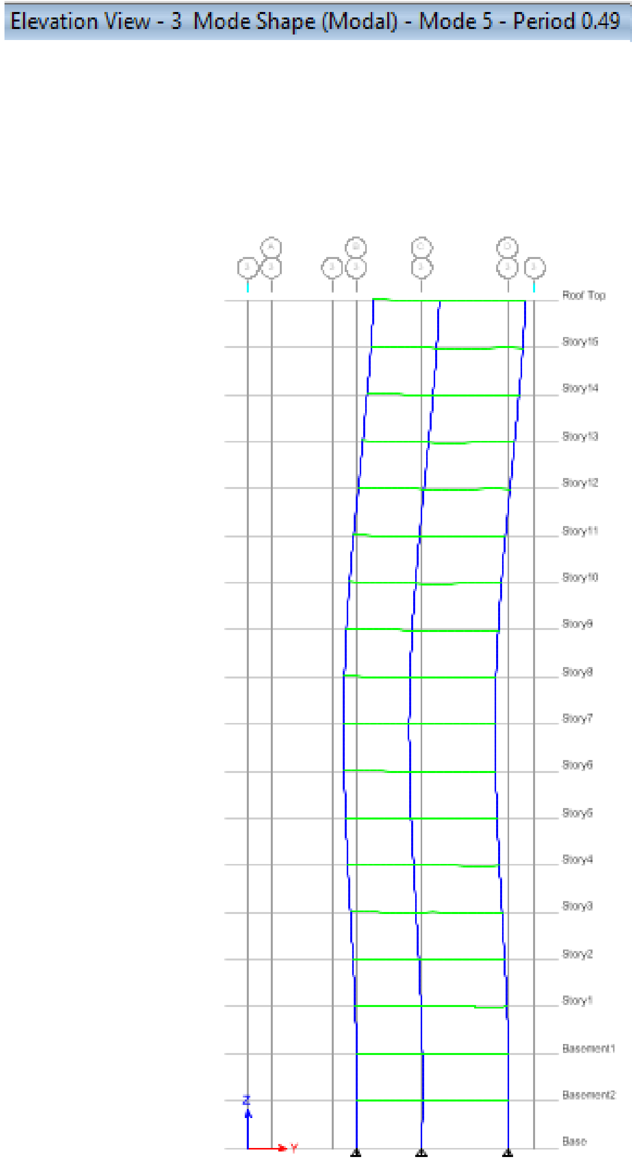

Figure 4.25 Composite Structure Mode Shape5 on axis 3

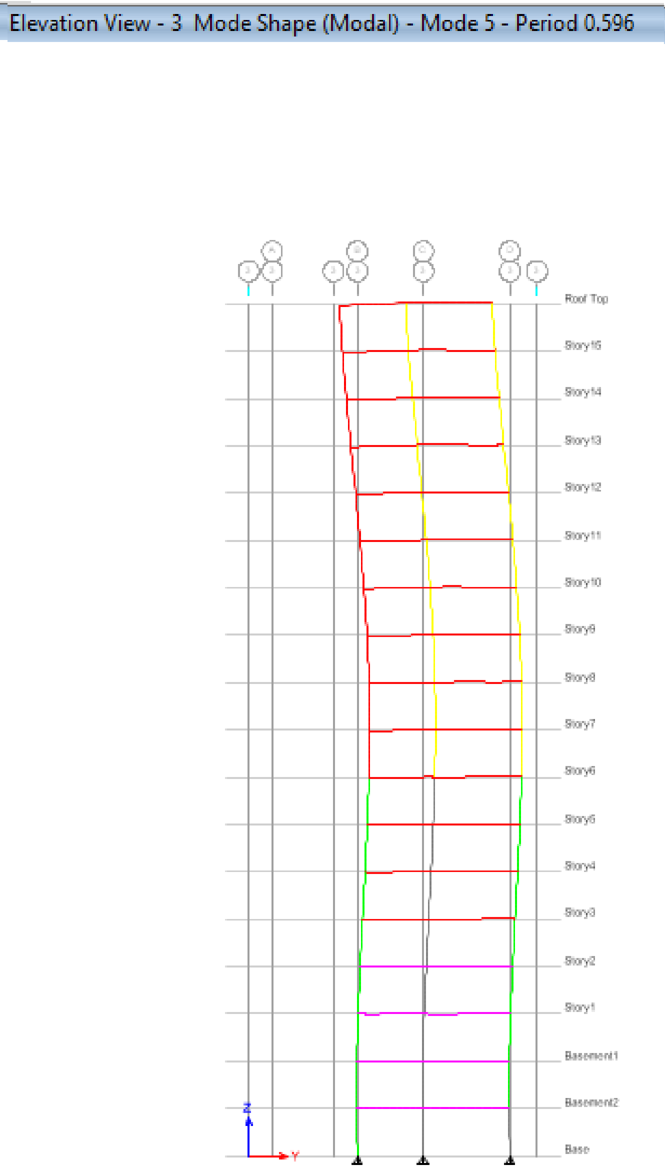

Figure 4.24 RC Structure Mode Shape5 on axis 3

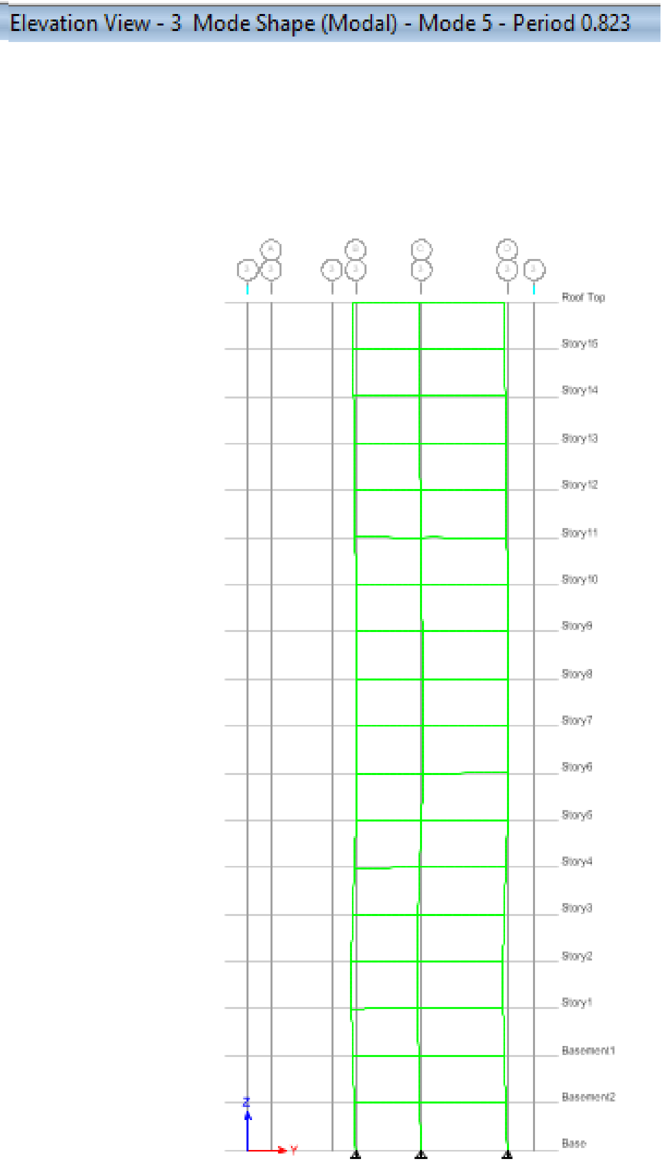

Figure 4.26 Steel Structure Mode Shape5 on axis 3

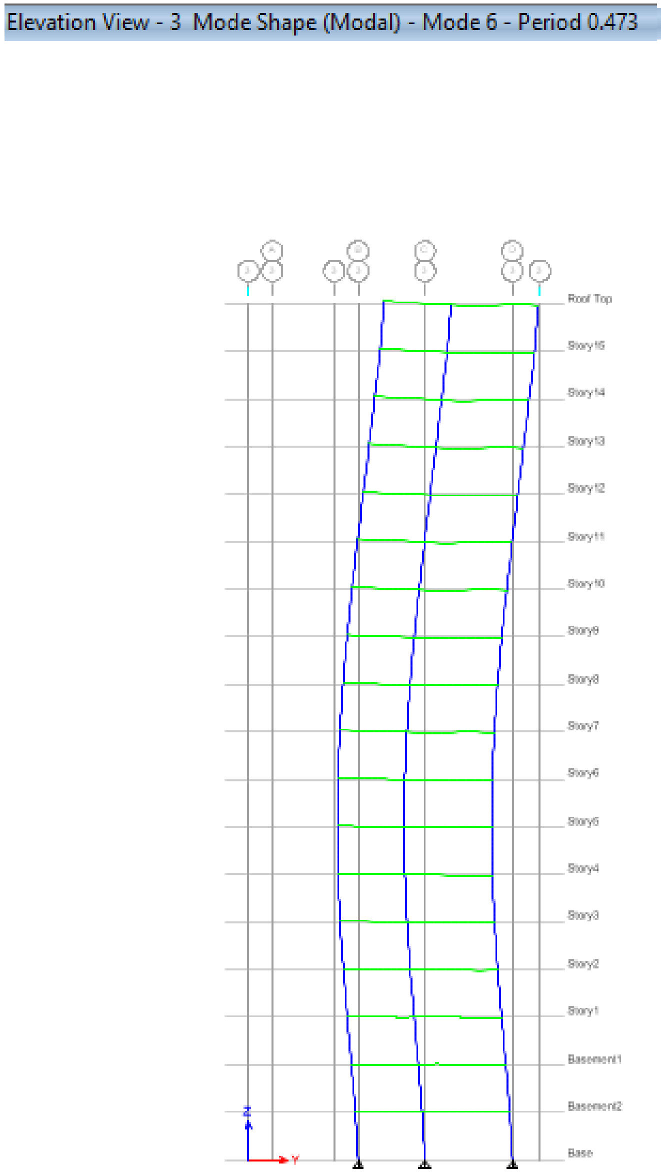

Figure 4.27 Composite Structure Mode Shape6 on axis 3

Figure 4.28 RC Structure Mode Shape6 on axis 3

Figure 4.29 Steel Structure Mode Shape6 on axis 3

Chapter 5
CONCLUSION

5.1. Introduction

Comparative study has been performed using all data obtained from load calculation, structural modeling, analysis, design, using ETABS 2016. Dynamic analysis is used using response spectrum.

Three structure types Composite, steel and RC for Addis Ababa housing project are compared. From the comparative study of these structures analyzed in chapter four above and findings are obtained. Based on these findings, final conclusions are drawn and presented in the following sections.

5.2. Conclusions

From the comparative study of the three types of structure with same floor system building; major findings and conclusions about Time period, Deflection, Base shear, story shear and maximum axial load are as follows.

5.2.1. RC Structure

Major conclusions are as follows**:**

- When using RC structure the fundamental period (First mode time period) of RC structure is about 36% lower than steel structure and 16% higher than Composite structure.
- The maximum roof displacement for the X-direction for RC structure is 41% lower than steel structure and 26% higher than that of Composite structure. The maximum roof displacement for the Y-direction for RC structure is 55% lower than steel structure and 31% higher than that of Composite structure.
- The maximum Story stiffness for the X-direction for RC structure is 45% higher than steel structure and 11% lower than that of composite structure. Steel structure is more ductile so this result is expected**.** The maximum Story stiffness for the Y-direction for RC structure is 36% higher than steel structure and 19% lower than that of Composite structure. Steel structure is more ductile so this result is expected.

- RC Structure for earthquake response in the X-direction base shear shows 1.1% decrease when compared to the composite structure. For earthquake response in the y-direction the base shear in RC structure shows 4.8% increase when compared composite structure.
- The maximum axial load for RC structure is 18% higher than steel structure and 11% higher than that of Composite structure.

5.2.2. Steel Structure

- When using steel structure the fundamental period (First mode time period) of steel structure is about 36% higher than RC structure and 20% higher than Composite structure.
- The maximum roof displacement for the X-direction for steel structure is 41% higher than RC structure and 15% higher than that of Composite structure. The maximum roof displacement for the Y-direction for steel structure is 55% higher than RC structure and 24% higher than that of Composite structure.
- The maximum Story stiffness for the X-direction for steel structure is 51% lower than Composite structure and 45% lower than that of RC structure. The maximum Story stiffness for the Y-direction for steel structure is 49% lower than composite structure and 36% lower than that of RC structure.
- Steel Structure for earthquake response in the X-direction base shear shows 34% decrease when compared to the composite structure. For earthquake response in the y-direction the base shear in steel structure shows 25% decrease when compared composite structure.
- The maximum axial load for steel structure is 7% lower than composite structure and 18% lower than that of RC structure.

5.2.3. Composite Structure

- When using RC structure the fundamental period (First mode time period) of Composite structure is about 20% lower than steel structure and 16% lower than RC structure.
- The maximum roof displacement for the X-direction for composite structure is 15% lower than steel structure and 26% lower than that of RC structure. The maximum

roof displacement for the Y-direction for composite structure is 31% lower than RCC structure and 24% lower than that of steel structure.

- The maximum Story stiffness for the X-direction for composite structure is 51% higher than steel structure and 11% higher than that of RC structure. The maximum Story stiffness for the Y-direction for composite structure is 49% higher than steel structure and 19% higher than that of RC structure.
- Composite Structure for earthquake response in the X-direction base shear shows 1.1% increase when compared to the RC. For earthquake response in the y-direction the base shear in composite structure shows 4.8% decrease when compared RC structure.
- The maximum axial load for composite structure is 11% lower than RC structure and 7% higher than that of steel structure.

5.3. Final Remarks

From the stand point of Seismic response, Composite structural system is the most suitable one. The maximum deflection is low compared to the two structures (steel and RC). The weight of structure of RCC Structure is high compared to steel and composite structure due to this the maximum axial load is high.

The analysis shows composite structure is stiffer than steel and RC. Because of these the roof lateral deflection is less in composite structure.

Steel structure which is more ductile attracts less seismic force. And RC structure is heavy which attracts seismic force. This will increase the base shear of the system. RC structural system is not a good choice for heavy structures in seismic active zone.

Cost of steel structure is less as compared to steel and composite structure. Cost of steel structure is 22% lower than RC structure and 18% lower than composite structure. And cost of composite structure is 5% lower than RC structure.

To adapt steel concrete composite material in large projects Local industries in the country have to sustain the demand of the construction industry. This technology is not practiced in Ethiopia due to different reasons. If the industry can provide quality steel in different section using composite structures is logical. Structural Engineers in the country have mastered RC structures but they need to improve their ability to design composite structures.

Finally, Composite structure system which optimizes economy, serviceability, construction time and seismic performance may be considered as optimum structural system for G+ 15 condominiums building in Addis Ababa.

5.4. Recommendation

Generally to achieve the objectives of constructions in economical way, composite structure design and construction technology plays enormous role. Developing countries has to give especial attention to get its benefit. Specifically, Ethiopia is one of the developing countries, and its economy is developing rapidly. Thus, this construction technology contributes a lot in the current context of the country to answer the demand of economical designs.

As mentioned in the literatures, even though local industries have been manufacturing steel structure this steel products are not highly used for structures. Therefore, government bodies have to introduce composite structure technology by preparing seminars and other means of communication. And local factories need to expand their ability to manufacture and import steel structural members of different size. As a result, the country might save lots of foreign currency by using local industries products to grow country's economy, and makes these industries to be competitive in the global market. Lastly, we strongly recommend this technology. Based on the abovementioned advantages, it would be interesting to continue and contribute in this area of research.

REFERENCE

[1] Handbook of Structural Engineering. CRC Press. 1997. ISBN 978-0-8493-2674-5.

[2]Armstrong, Robert (7 March 2014). "Properties and Prevention of Household Mold" Absolute Steel Retrieved 2 November 2014.

[3] Ethiopian Building Code Standard: EBCS-4(1995):Design of Composite Steel and Concrete structures. Addis Ababa: Ministry of Works and Urban Development.

[4] Taranath,Bungale. “Reinforced Concrete Design of Tall Buildings”. ISBN 978-1-4398-0480-3.

[5] Kumawat. M “Analysis and Design of Multistory Building Using Composite Structure”, International Journal of Structural and Civil Engineering Research, ISSN 2319-6009, Vol.3, No.2 (May-2014)

[6] Prof. S.S. Charantimath, “Comparative Study on Structural Parameter of R.C.C. and Composite Building”, Civil and Environmental Research ISSN 2224-5790, Vol.6, No. 6, (2014)

[7] Pro. Swapnil B., “Comparative Analysis of Multistoried RCC and Composite Building due to Mass Irregularity” International Research Journal of Engineering And Technology, Vol. 02, Issue : 04 (July-2015)

[8] Patil V., “Comparative Study on Dynamic Analysis of Composite, RCC & Steel Structure”, International Journal of Engineering Technology, Management and Applied Sciences, Volume 3, Issue 8(August-2015)

[9] Jirage D., Prof.V.G.Sayagavi, prof.N.G.Gore,” Comparative Study of RCC and Composite Multi-storeied Building”, International Journal of Scientific Engineering and Applied Science(USEAS), Vol.1, Issue:6 (Sep. 2015)

[10] Najia A., “Dynamic Response of RCC and Composite Structure with Brb Subjected to Seismic and Temperature Load” International journal of Engineering Research and Applications, Vol. 6m Issue:4part 4(April-2016)

[11] Kumar M., “Seismic Analysis of Steel Concrete Composite System and its Contrast with RCC Structures”, International Journal of Science and Research, Vol.5, Issue: 8 (August-2016)

[12] Koppad S., Dr. S.B. Itti “Comparative Sturdy of RCC and Composite Multistoried Buildings” International Journal of Engineering and Innovative Technology, Vol. 5, Issue: 5 (November-2013)

[13] Aniket R., SuryawanshiYogesh, “Comparative Study on Analysis and Cost of R.C.C and Steel- Composite Structure”, International Journal of Science and Research, Vol. 5, Issue: 7 (July-2016)

[14] Begum M., “Cost Analysis of Steel Concrete Composite Structures in Bangladish”, Asian Journal of Civil Engineering, Vol.14, No.6 (April-2013)

[15] Ethiopian Building Code Standard:EBCS-8(1995):DESIGN OF STRUCTURES FOR EARTHQUAKE RESISTANCE. Addis Ababa: Ministry of Works and Urban Development.

[16] Ethiopian Building Code Standard:EBCS-3(1995):DESIGN OF STEEL STRUCTURES. Addis Ababa: Ministry of Works and Urban Development.

[17] Ethiopian Building Code Standard:EBCS-4(1995):Design of Composite Steel and Concrete structures. Addis Ababa: Ministry of Works and Urban Development.

[18] Tedia, A. (2014). Cost, Analysis and Design of Steel-Concrete Composite. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , 11 (1), 54-59.

[19] Eurocode-3 “Design of Steel Structures”, European Committee for Standardization Committee European De Normalization European SchesCommittee Fur Forming (2004)

[20] Eurocode-4 “Design of Composite Steel and Concrete Structures”, European Committee for Standardization Committee European De Normalization European Sches Committee Fur Forming (2004)

[21] Redie, R., "A Study on the suitability of local steel profiles for the production of steel deck Reinforced composite slabs for building" Addis Ababa University Faculty of Technology, (2003)

[22] Bass B., ''Cost Effectiveness of Composite Frames in Condominium Houses" Addis Ababa University. (March-2016)

Appendix

A1. RC Structure Design Section

Table A-1 RC Structure Design Section

Story	Design Type	Analysis Section	Story	Design Type	Design Section
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x50cm
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x50cm
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x50cm
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x50cm
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x40cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 70x70cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 70x70cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 70x70cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 70x70cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 70x70cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 60x60cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 70x70cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 70x70cm
Roof top	Column	Col 60x50cm	Story6	Column	Col 60x50cm
Story15	Column	Col 60x40cm	Story5	Column	Col 60x50cm
Story15	Column	Col 60x40cm	Story5	Column	Col 60x50cm
Story15	Column	Col 60x40cm	Story5	Column	Col 60x50cm
Story15	Column	Col 60x40cm	Story5	Column	Col 60x50cm
Story15	Column	Col 60x40cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x40cm	Story5	Column	Col 60x60cm

Story15	Column	Col 60x40cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x40cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x40cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x50cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x50cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x50cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x50cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x50cm	Story5	Column	Col 70x70cm
Story15	Column	Col 60x50cm	Story5	Column	Col 70x70cm
Story15	Column	Col 60x50cm	Story5	Column	Col 70x70cm
Story15	Column	Col 60x50cm	Story5	Column	Col 70x70cm
Story15	Column	Col 60x50cm	Story5	Column	Col 70x70cm
Story15	Column	Col 60x50cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x50cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x50cm	Story5	Column	Col 60x60cm
Story15	Column	Col 60x50cm	Story5	Column	Col 70x70cm
Story15	Column	Col 60x50cm	Story5	Column	Col 70x70cm
Story15	Column	Col 60x50cm	Story5	Column	Col 60x50cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x50cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x50cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x50cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x50cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x40cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x50cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x50cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x50cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x50cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x50cm	Story4	Column	Col 70x70cm
Story14	Column	Col 60x50cm	Story4	Column	Col 70x70cm
Story14	Column	Col 60x50cm	Story4	Column	Col 70x70cm
Story14	Column	Col 60x50cm	Story4	Column	Col 70x70cm

Story14	Column	Col 60x50cm	Story4	Column	Col 70x70cm
Story14	Column	Col 60x50cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x50cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x50cm	Story4	Column	Col 60x60cm
Story14	Column	Col 60x50cm	Story4	Column	Col 70x70cm
Story14	Column	Col 60x50cm	Story4	Column	Col 70x70cm
Story14	Column	Col 60x50cm	Story4	Column	Col 60x50cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x50cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x50cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x50cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x50cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x40cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x50cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x50cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x50cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x50cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x50cm	Story3	Column	Col 70x70cm
Story13	Column	Col 60x50cm	Story3	Column	Col 70x70cm
Story13	Column	Col 60x50cm	Story3	Column	Col 70x70cm
Story13	Column	Col 60x50cm	Story3	Column	Col 70x70cm
Story13	Column	Col 60x50cm	Story3	Column	Col 70x70cm
Story13	Column	Col 60x50cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x50cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x50cm	Story3	Column	Col 60x60cm
Story13	Column	Col 60x50cm	Story3	Column	Col 70x70cm
Story13	Column	Col 60x50cm	Story3	Column	Col 70x70cm
Story13	Column	Col 60x50cm	Story3	Column	Col 60x50cm
Story12	Column	Col 60x40cm	Story2	Column	Col 60x50cm
Story12	Column	Col 60x40cm	Story2	Column	Col 60x50cm
Story12	Column	Col 60x40cm	Story2	Column	Col 60x50cm
Story12	Column	Col 60x40cm	Story2	Column	Col 60x50cm

Story12	Column	Col 60x40cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x40cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x40cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x40cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x40cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x50cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x50cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x50cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x50cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x50cm	Story2	Column	Col 70x70cm
Story12	Column	Col 60x50cm	Story2	Column	Col 70x70cm
Story12	Column	Col 60x50cm	Story2	Column	Col 70x70cm
Story12	Column	Col 60x50cm	Story2	Column	Col 70x70cm
Story12	Column	Col 60x50cm	Story2	Column	Col 70x70cm
Story12	Column	Col 60x50cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x50cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x50cm	Story2	Column	Col 60x60cm
Story12	Column	Col 60x50cm	Story2	Column	Col 70x70cm
Story12	Column	Col 60x50cm	Story2	Column	Col 70x70cm
Story12	Column	Col 60x50cm	Story2	Column	Col 60x50cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x50cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x50cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x50cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x50cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x40cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x50cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x50cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x50cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x50cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x50cm	Story1	Column	Col 70x70cm
Story11	Column	Col 60x50cm	Story1	Column	Col 70x70cm

Story11	Column	Col 60x50cm	Story1	Column	Col 70x70cm
Story11	Column	Col 60x50cm	Story1	Column	Col 70x70cm
Story11	Column	Col 60x50cm	Story1	Column	Col 70x70cm
Story11	Column	Col 60x50cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x50cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x50cm	Story1	Column	Col 60x60cm
Story11	Column	Col 60x50cm	Story1	Column	Col 70x70cm
Story11	Column	Col 60x50cm	Story1	Column	Col 70x70cm
Story11	Column	Col 60x50cm	Story1	Column	Col 60x50cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x50cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x50cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x50cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x50cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x40cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 70x70cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 70x70cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 70x70cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 70x70cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 70x70cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 60x60cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 70x70cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 70x70cm
Story10	Column	Col 60x50cm	Basement 1	Column	Col 60x50cm
Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x50cm
Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x50cm

Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x50cm
Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x50cm
Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x40cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 60x60cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 70x70cm
Story9	Column	Col 60x50cm	Basement 2	Column	Col 60x50cm
Story8	Column	Col 60x40cm	Roof top	Beam	Beam25x50cm
Story8	Column	Col 60x40cm	Story15	Beam	Beam25x50cm
Story8	Column	Col 60x40cm	Story14	Beam	Beam25x50cm
Story8	Column	Col 60x40cm	Story13	Beam	Beam25x50cm
Story8	Column	Col 60x40cm	Story12	Beam	Beam25x50cm
Story8	Column	Col 60x40cm	Story11	Beam	Beam25x50cm
Story8	Column	Col 60x40cm	Story10	Beam	Beam25x50cm
Story8	Column	Col 60x40cm	Story9	Beam	Beam25x50cm
Story8	Column	Col 60x40cm	Story8	Beam	Beam25x50cm
Story8	Column	Col 60x50cm	Story7	Beam	Beam25x50cm
Story8	Column	Col 60x50cm	Story6	Beam	Beam25x50cm
Story8	Column	Col 60x50cm	Story5	Beam	Beam25x50cm
Story8	Column	Col 60x50cm	Story4	Beam	Beam25x50cm

Story8	Column	Col 60x50cm	Story3	Beam	Beam25x50cm
Story8	Column	Col 60x50cm	Story2	Beam	Beam 30x50cm
Story8	Column	Col 60x50cm	Story1	Beam	Beam 30x50cm
Story8	Column	Col 60x50cm	Basement 1	Beam	Beam 30x50cm
Story8	Column	Col 60x50cm	Basement 2	Beam	Beam 30x50cm
Story8	Column	Col 60x50cm			
Story8	Column	Col 60x50cm			
Story8	Column	Col 60x50cm			
Story8	Column	Col 60x50cm			
Story8	Column	Col 60x50cm			
Story8	Column	Col 60x50cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x40cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			
Story7	Column	Col 60x50cm			

A2. Steel Structure Design Section

Table A-2 Steel Structure Design Section

Story	Design type	Section Type	Design Section
Roof Top	Column	Auto Select	HE100A
Story15	Column	Auto Select	H400X237, HE340B, H400X288, H400X347, H400X463, HE340B, HE450B
Story14	Column	Auto Select	HE200B, HE160A, H400X237, HE 240B, HE160B, HE180B
Story13	Column	Auto Select	H400X237, HE500A, HE360B, HE300B, HE340B, H400X463, H400X340
Story12	Column	Auto Select	HE240B, HE180B, H400X262, HE220B, HE240B, HE300B, HE 280B
Story11	Column	Auto Select	H400X237, HE360B, HE160B, HE500A, HE320B, H400X262, HE400B
Story10	Column	Auto Select	HE280B, HE220B, HE340B. HE200B, HE240B. HE320B, H400.X340, H400C262
Story9	Column	Auto Select	H400X237, HE360B, HE400B, HE160B, HE340, HE450, HE220B, H400X463, HE360A
Story8	Column	Auto Select	HE360A, HE240B, HE500A, HE220B,HE300C,HE340A, H400X288, H400X393, H400347
Story7	Column	Auto Select	H400X262, HE340B, HE180B, HE450B, HE360B, HE260B,H400X463, H400X509
Story6	Column	Auto Select	HE400A, HE260B, HE500A, HE240B, HE400B, HE340B, HE220m H400X237m H400X262, H400X314, H400X383m HE450B
Story5	Column	Auto Select	H400X262, HE450B, HE200B, HE450B, HE260B, H400X288, H400X314, HE280B, HE400B, HE500B, HE550B, HE550A, HE200B
Story4	Column	Auto Select	HE400B, HE280B, HE500A, HE360A, H400X237, H400X262, HE450B, HE140A, HE340A

Story3	Column	Auto Select	H400X288, HE400B, HE220B, HE500B, HE280B, H400X314, HE340A, HE450B, HE300C, HE300B, H400X383, H400X237, H160B
Story2	Column	Auto Select	H400X237, HE300B, HE400B, HE280B, H400X422m H400X509,HE300C, HE500B, H400X262
Story1	Column	Auto Select	H400X237, HW220B, HE300C, HE300B, H400X340, H400X314, HE360A, HE500B, HE450B, HE500B, H280M
1st Basment	Column	Auto Select	H400X237, HW220B, HE300C, HE300B, H400X340, H400X314, HE360A, HE500B, HE450B, HE500B, H280M
2nd Basment	Column	Auto Select	H400X237, HW220B, HE300C, HE300B, H400X340, H400X314, HE360A, HE500B, HE450B, HE500B, H280M
Roof Top	Beam	Auto Select	W16X26, W12X26, W12X30
Story15	Beam	Auto Select	W12X26, W21X44, W14X38, W12X30,
Story14	Beam	Auto Select	W12X26, W24X62, W21X50, W14X34, W18X35
Story13	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story12	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story11	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story10	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story9	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story8	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story7	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story6	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story5	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story4	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story3	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26

Story2	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story1	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Basement 1	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Basement 2	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26

A3. Composite Structure Design Section

Table A-3 Composite Structure Design Section

Story	Design type	Section Type	Auto Section
Roof top	Column	Auto Select	Steel Section cased in concrete) (H400X237, H400X262, H400X288, H400X314, H400X340, H400X347, H400X383,H400x420, H400X463, H400X462, H400X818, H400X900, H400X990
Story15	Column	Auto Select	Steel Section cased in concrete) (H400X237, H400X262, H400X288, H400X314, H400X340, H400X347, H400X383,H400x420, H400X463, H400X462,
Story14	Column	Auto Select	Steel Section cased in concrete) (H400X237, H400X262, H400X288, H400X314, H400X340, H400X347, H400X383,H400x420, H400X463, H400X462,
Story13	Column	Auto Select	Steel Section cased in concrete) (H400X237, H400X262, H400X288, H400X314, H400X340, H400X347, H400X383,H400x420, H400X463, H400X462,
Story12	Column	Auto Select	Steel Section cased in concrete) (H400X237, H400X262, H400X288, H400X314, H400X340, H400X347, H400X383,H400x420, H400X463, H400X462,
Story11	Column	Auto Select	Steel Section cased in concrete) (H400X237, H400X262, H400X288, H400X314, H400X340, H400X347, H400X383,H400x420, H400X463, H400X462,
Story10	Column	Auto Select	com 11(H400X462steel section in cased in concrete)
Story9	Column	Auto Select	com 11(H400X462steel section in cased in concrete)
Story8	Column	Auto Select	com 11(H400X462steel section in cased in concrete)
Story7	Column	Auto Select	com 11(H400X462steel section in cased in concrete)
Story6	Column	Auto Select	Steel Section in cased in concrete H400X551, H400X593, H400X634, H400X678,

			H400X744, H400X818, H400X900, H400X990
Story5	Column	Auto Select	Steel Section in cased in concrete H400X551, H400X593, H400X634, H400X678, H400X744, H400X818, H400X900, H400X990
Story4	Column	Auto Select	Steel Section in cased in concrete H400X551, H400X593, H400X634, H400X678, H400X744, H400X818, H400X900, H400X990
Story3	Column	Auto Select	Steel Section in cased in concrete H400X551, H400X593, H400X634, H400X678, H400X744, H400X818, H400X900, H400X990
Story2	Column	Auto Select	Steel Section in cased in concrete H400X551, H400X593, H400X634, H400X678, H400X744, H400X818, H400X900, H400X990
Story1	Column	Auto Select	Steel Section in cased in concrete H400X551, H400X593, H400X634, H400X678, H400X744, H400X818, H400X900, H400X990
Basement 1	Column	Auto Select	Steel Section in cased in concrete H400X551, H400X593, H400X634, H400X678, H400X744, H400X818, H400X900, H400X990
Basement 2	Column	Auto Select	Steel Section in cased in concrete H400X551, H400X593, H400X634, H400X678, H400X744, H400X818, H400X900, H400X990
Roof top	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story15	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story14	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story13	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story12	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story11	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story10	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story9	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story8	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story7	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story6	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story5	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story4	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story3	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26

Story2	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Story1	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Basement 1	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26
Basement 2	Beam	Auto Select	W12X26, W24X55, W12X30, W21X50, W14X34, W16X26